

This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

EEncT 218.83.485
J.N.Y.S.
JAN 10 191
B 3 3

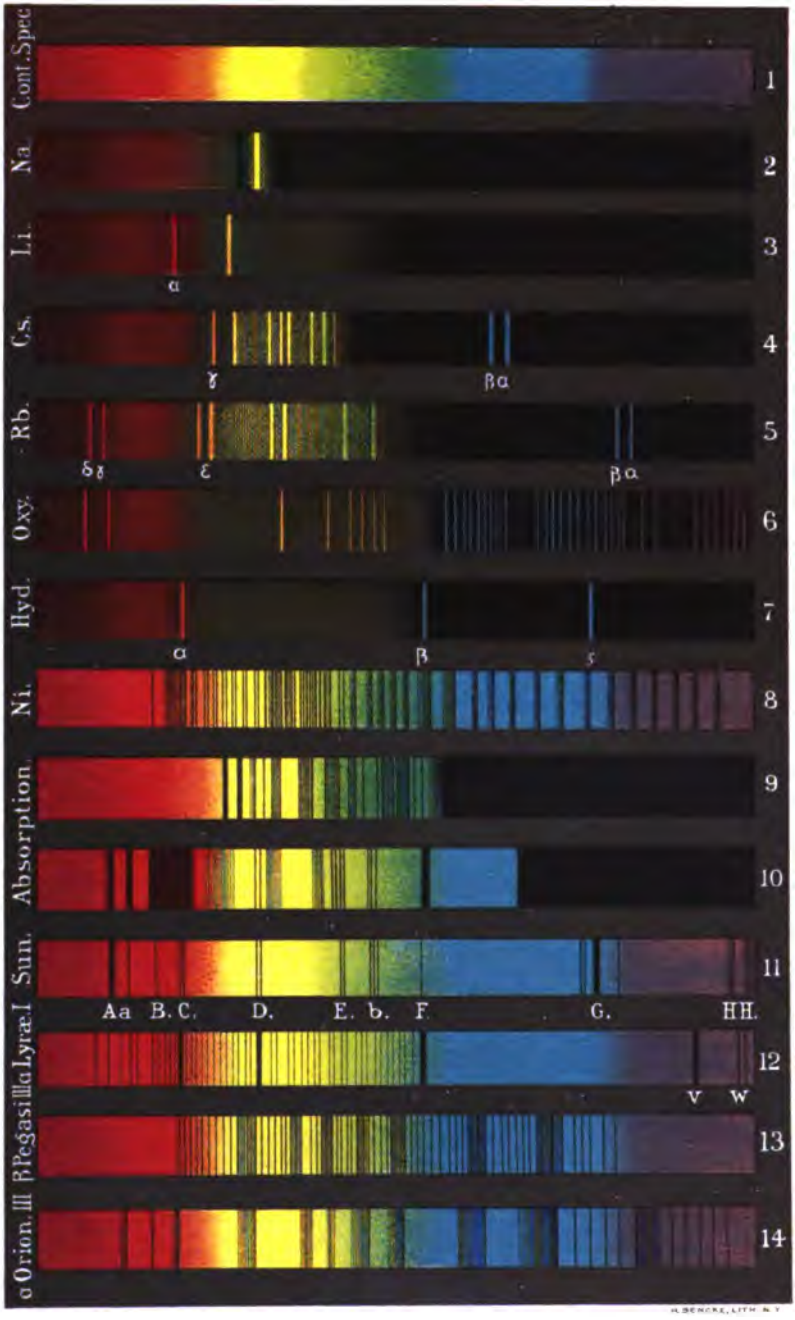
Harvard College
Library



By Exchange

3 2044 097 016 265

TABLE OF SPECTRA.



EEncT 218.83.485
JAN 10 191
B3B

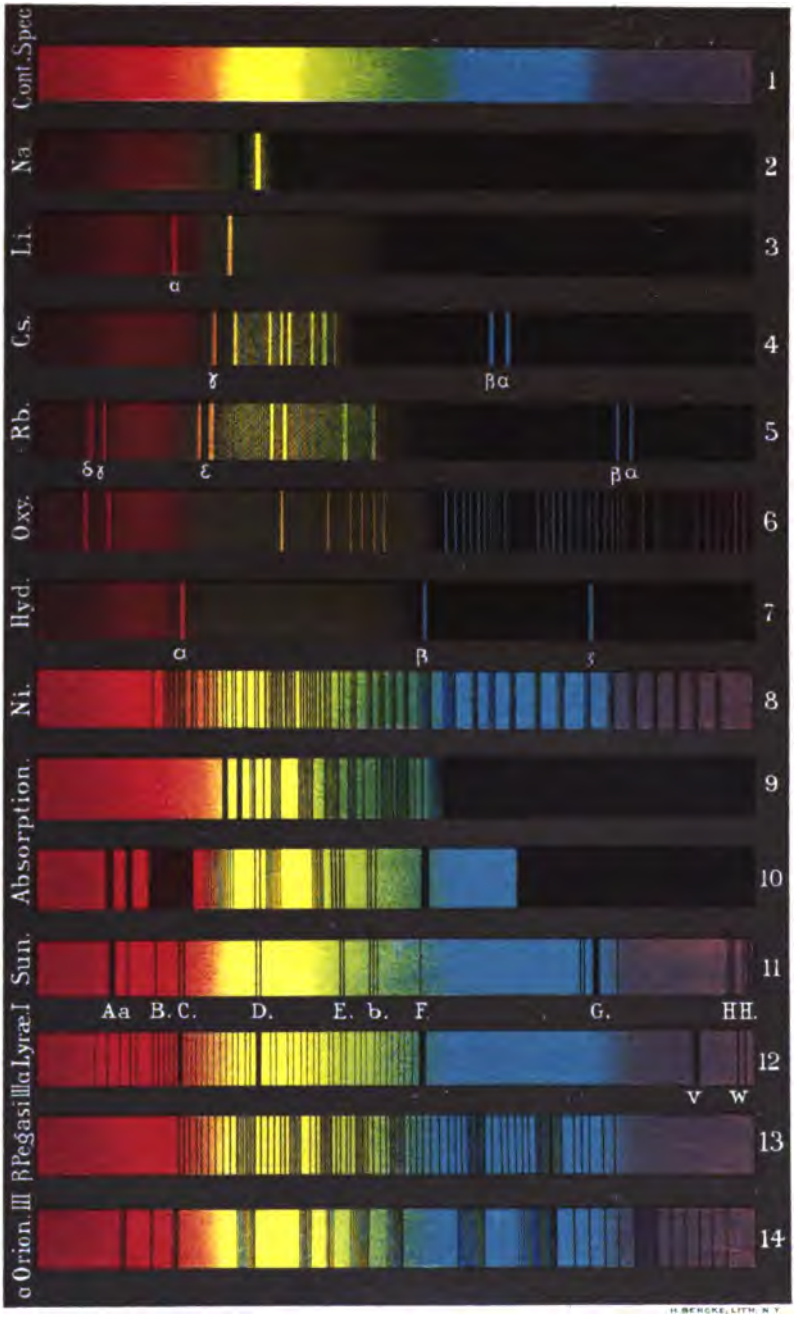
Harvard College
Library



By Exchange

3 2044 097 016 265

TABLE OF SPECTRA.



A

TEXT-BOOK

ON

PHYSICS

BEING

A SHORT AND COMPLETE COURSE

BASED UPON THE LARGER WORK OF GANOT

FOR THE USE OF ACADEMIES, HIGH SCHOOLS, &c.

BY

HENRY KIDDLE, A.M.

LATE SUPERINTENDENT OF SCHOOLS, NEW YORK CITY.

Illustrated by Three Colored Plates and Two Hundred and Ninety-five Woodcuts

NEW YORK

WILLIAM WOOD & COMPANY

56 AND 58 LAFAYETTE PLACE

1883

FincT 218.83.485

HARVARD COLLEGE LIBRARY
BY EXCHANGE FROM
NEW YORK STATE LIBRARY
FEB [illegible] 12

COPYRIGHT BY
WILLIAM WOOD & COMPANY
1883

TROW'S
PRINTING AND BOOKBINDING COMPANY
201–213 *East Twelfth Street*
NEW YORK

PREFACE.

As an exposition of the principles of physical science, adapted to the purposes of education, Ganot's *Élements de Physique* has strong claims to preference over other works of the kind. It has passed through numerous editions, and has been translated into several European languages,—its methodical arrangement and scientific accuracy, as well as the clearness of its definitions and explanations, rendering it a standard work of the kind.

Professor Atkinson's admirable English translation, embodying all that is required for an extensive college course, and including the applications of the higher mathematics to the subject, has been very extensively used both in this country and in England, and is at present generally acknowledged to be the most valuable and popular textbook of its class.

The severely scientific character of this work, however, necessarily renders it unsuitable for use in elementary schools, in which instruction in mathematics is confined within the ordinary limits of a rudimental course. The present work is designed to meet the wants of such schools by supplying a brief treatise, containing an exposition of the fundamental principles of physical science as laid down by Ganot, and with the admirably lucid illustrations and experimental demonstrations supplied in his larger work.

It has been, therefore, the aim of the editor and compiler of this work, while stating the elementary definitions and principles as clearly and concisely as possible, and distinguishing them from illustrative and subordinate matter, to adhere, as far as was practicable, to the text

of the larger work, so that this elementary manual might be conveniently used as an introduction thereto, without necessitating the relearning of these rudimental parts.

The selection of illustrations from those of the larger work has been governed by the consideration of simplicity and utility; and the explanations have been made as brief as perspicuity would permit, since young students are apt to be repelled by prolix descriptions, which after all can not, properly or effectively, supersede the constant use of the apparatus itself.

The Synopses are designed to furnish a ready method of topical review, and hence have been made fully exhaustive of the text. The arrangement in each presents a clear analysis of that part of the subject to which it refers; and thus, while serving to fix in the mind of the student the logical relations of the different topics, can not fail to be serviceable to the instructor both for examination and drill.

The Applications of Principles are intended to supply an exercise which can readily be extended by the intelligent teacher, the student being encouraged to find material for similar inquiry. Success in teaching this subject depends very much upon the degree in which the pupil's mind is awakened to such a spirit of investigation.

The Problems for Exercise have been made sufficiently simple to be solved by students who possess but an elementary knowledge of mathematics, and will serve still further to discipline the mind in this kind of inquiry, as well as to apply the principles acquired.

The English system of weights and measures has been substituted for the metric system as better adapted for so elementary a work. The Fahrenheit thermometer is chiefly referred to, although the method of conversion into Centigrade degrees has been fully explained.

NEW YORK, August 1, 1883.

CONTENTS.

CHAPTER I.

MATTER, FORCE, AND MOTION.

PAGE

I.—General Principles, ... 9
II.—Properties of Bodies, ... 11
III.—Force, Equilibrium, and Motion, ... 14
IV.—Simple Machines, ... 17
V.—Motion, ... 23
VI.—The Pendulum, ... 25
VII.—Impulsive Forces, ... 26
VIII.—Work and Energy, ... 27

CHAPTER II.

GRAVITATION AND MOLECULAR ATTRACTION.

I.—Universal Gravitation, Gravity, and Equilibrium, . . 32
II.—Weight, ... 39
III.—Molecular Forces, ... 40
IV.—Properties Peculiar to Solids, ... 41

CHAPTER III.

LIQUIDS.

I.—Hydrostatics, ... 45
II.—Specific Gravity, ... 55
III.—Capillary Attraction, ... 57
IV.—Endosmose and Exosmose, ... 60
V.—Diffusion of Liquids, ... 61
VI.—Water Power, ... 61
VII.—Phenomena of Jets, ... 62

CHAPTER IV.

GASES.

PAGE

I.—Properties of Gases, ... 66
II.—The Atmosphere, ... 67
III.—The Barometer, ... 70
IV.—Law of the Compressibility of Gases, ... 73
V.—Pressure upon Bodies in Air-Balloons, ... 74
VI.—Air-Pump and Other Apparatus, ... 76

CHAPTER V.

ACOUSTICS.

I.—Production, Propagation, and Reflection of Sound, . 85
II.—Measurement of the Number of Vibrations, . . . 90
III.—Physical Theory of Music, ... 93
IV.—Analysis and Representation of Vibrations, . . . 97
V.—The Human Voice and Ear, ... 105

CHAPTER VI.

HEAT.

I.—Nature and General Effects of Heat, ... 109
II.—Temperature and its Measurement, ... 111
III.—Expansion of Bodies by Heat, ... 113
IV.—Changes of Condition. Vapors, ... 116
V.—Transmission of Heat, ... 120
VI.—Calorimetry, ... 125
VII.—The Steam-Engine, ... 126
VIII.—Sources of Heat, ... 129

CHAPTER VII.

LIGHT.

I.—Origin, Transmission, and Intensity of Light, . . . 134
II.—Reflection of Light. Mirrors, ... 138
III.—Refraction of Light. Lenses, ... 146
IV.—Composition of Light. Colors, ... 155
V.—Optical Instruments, ... 165
VI.—Miscellaneous Phenomena, ... 176

CHAPTER VIII.

MAGNETISM.

PAGE
I.—Properties of Magnets, ... 186
II.—Terrestrial Magnetism, ... 191

CHAPTER IX.

FRICTIONAL ELECTRICITY.

I.—Phenomena and Laws of Electrical Action, ... 195
II.—Electrical Apparatus, ... 202
III.—Accumulation and Condensation of Electricity, . . 208

CHAPTER X.

GALVANIC OR DYNAMICAL ELECTRICITY.

I.—Galvanic or Voltaic Batteries, ... 218
II.—Effects and Uses of the Voltaic Current, ... 223
III.—Electro-Magnetism, ... 228
IV.—Voltaic Induction. Magneto-Electricity, ... 235
V.—Thermo-Electricity, ... 243
VI.—Animal Electricity, ... 244

CHAPTER XI.

METEOROLOGY.

Winds, ... 248
Atmospheric Pressure, ... 249
Fogs and Mists, Clouds, Rain, etc., ... 250
Atmospheric Phenomena, ... 254
Climate, ... 255
Registration of Phenomena, ... 256

Index, ... 257

SUGGESTIONS TO TEACHERS.

EFFECTIVE teaching requires not only a knowledge of the subject to be taught, but a correct understanding of its relations to the mind—the faculties which it especially addresses, and calls into exercise. In this regard every branch of instruction has its own peculiar field. Physics, or experimental philosophy, is peculiarly a science of causes and effects, and the mental faculty which its study chiefly brings into play is inductive reasoning, based on the facts of observation and experiment.

Hence, the pupil should, at every step, be made attentive to the facts and the means by which they have been ascertained, and should be trained to reason correctly upon them—at any rate, to see clearly how they support the principles derived from them. A mere mechanical study and recitation may serve to fill the memory with facts obtained by the observation and reasoning of other minds, but will not promote the requisite mental discipline, unless the student is trained to collect facts by his own observation and experiment, and made to reason correctly upon them.

At every stage, therefore, the principles and laws presented should be illustrated by facts of the pupil's own experience—such as the commonest observations often afford, and which need only attention and intelligence to render interesting illustrations of important principles. If the pupil has had no experience of any particular class of phenomena under consideration—of polarised light or electrical induction, for example—it must be imparted by the instructor through the agency of a carefully arranged series of experiments, which the pupil should be required to duplicate himself by the use of the apparatus.

The figures and diagrams representing the apparatus are illustrative only in a secondary degree, and cannot wholly take the place of apparatus designed for primary exposition or illustration. The student should be accustomed to the use of these, and should constantly be required to explain the processes, and the principles or facts which they serve to exemplify or to prove. Drawing diagrams on the blackboard may help to deepen the impressions formed from them; but this will not, necessarily, make the student's ideas of the principles more clear or comprehensive, or supersede the necessity of actual observation and experiment.

The primary principles, laws, and definitions, clearly and concisely expressed, should be accurately fixed in the memory, so that they may be readily referred to. If the pupil can find as good or a better form of expression for them than that given in the text-book, he should be permitted, and even encouraged, to use it; but accuracy and definiteness should always be insisted upon, and the habit of slovenly and inaccurate statement carefully avoided. In this work, the numbered articles, in larger type, contain the most important definitions and principles, and with these the pupil's mind should be thoroughly familiarized. Of the subordinate matter, in smaller print, the substance only need be given in recitation, with less attention to absolute accuracy of expression.

Connected statements relating to particular topics should be required of the pupil rather than answers to minute questions, although the latter are not to be dispensed with altogether. After the pupil has stated all that he can upon the topic assigned, and in the best manner as to arrangement and style of expression, the teacher, by skillful questioning, will be able to accomplish very much toward rendering the imperfect ideas of the pupil more clear, definite, and accurate, and putting the subject in a better and stronger position in his mind.

The synopsis given at the end of each chapter will be found to contain an analysis of every topic, and can be used as a guide in recitation as well as for examination and review. The synopsis of that part of the subject from which the pupils are to recite may be written on the blackboard, and the recitation proceed without questioning by the teacher. Much is gained by throwing the learner on his own resources, aid being afforded only when it is needed, and when the pupil feels its need.

The practical exemplification of principles should be carefully attended to, the examples given being employed only to stimulate the pupils' minds in that direction, and excite to observation and reflection. Others will then be readily found. So in regard to apparatus: the pupil should be encouraged to experiment with the simple means and appliances at his own command, or with such as he can exercise his constructive ingenuity in preparing. The union of the *executive* faculties with the reflective has the greatest importance in education—from the kindergarten to the high school, or even college.

The pupil should be encouraged to search, in larger works, for ampler statements, fuller illustrations, and more extensive knowledge of the various subjects treated. It is more important to impart a taste for a particular branch of knowledge than to teach any number of facts pertaining to it; for the mind, under such a spur, rapidly makes acquisitions.

Solid, lasting results cannot be reached in haste; the study of a few weeks cannot be made so effective as to give a matured knowledge of the elementary principles of such a subject as physics. The pupil should not be encouraged to think so: but should be made to understand that only close and protracted attention, diligent reflection, and reviews many times repeated, will serve to fix in his mind principles and facts which he can render available in his future studies or in his future life.

PHYSICS.

CHAPTER I.

MATTER, FORCE, AND MOTION.

I.—GENERAL PRINCIPLES.

1. **Physics** is a branch of science that treats of the changes observed to take place in bodies. These changes are called *phenomena.*

The fall of a stone, the vibration of a string, the sound produced by it, the freezing of water, the melting of lead, are examples of *physical phenomena.*

Changes in the nature of the body itself, such as the decomposition of one body into others, are phenomena the study of which forms the immediate object of *Chemistry.* Physics, sometimes called *Natural Philosophy,* or *Mechanical Philosophy,* treats of matter in masses; Chemistry has regard to the elementary particles of which they are composed.

2. **Matter** is anything that has extension; or it is that the existence of which is made known by our senses. A *body* is any separate portion of matter.

All material substances are either elements, or chemical combinations of elements; that is, of substances that cannot be decomposed into others of a simpler character. The number of such elements at present known is sixty-seven. Gold, silver, iron, sulphur, and phosphorus are examples of elements.

3. **Atoms and Molecules.**—Matter is conceived to consist of an immense number of exceedingly small particles, called *atoms.* A group of atoms forms a *molecule.*

Atoms cannot be divided, and are held in position, without touching each other, by means of attractions and repulsions, called *molecular forces.* Thus every

body may be considered as an aggregate of molecules, and these again as aggregates of atoms. This is called the *Atomic Theory.**

The distance between the adjacent molecules of ordinary bodies has been estimated as less than the three hundred millionth part of an inch. If we imagine a drop of rain magnified to the size of the earth, the molecules, being proportionately increased, would then be no larger than an apple. That is to say, the molecules of a drop of water are as much smaller than an apple as a drop of water is smaller than the earth. The number of molecules in a cubic inch of water has been estimated at three hundred and fifty trillions; and the weight of an atom of hydrogen gas, at less than the thousand millionth part of a grain.

4. The **states of aggregation** presented by material substances are three: of solids, of liquids, and of gases.

5. **Solids** consist of molecules held firmly together by more or less force; as minerals, metals, wood, etc.

Solids, therefore, tend to retain whatever form may be given them by nature or art.

6. **Liquids** consist of molecules that move easily among themselves; as water, oil, alcohol, etc.

Hence a liquid readily assumes the form of the vessel into which it is poured.

7. **Gases** are substances the molecules of which tend to recede from each other by mutual repulsion.

The general term *fluid* is applied to both liquids and gases.

The same substance may exist in any of these three states. Of this, water presents a familiar example, in its frozen, liquid, and vaporous state.

8. A **physical law** is the constant relation which exists between any phenomenon and its cause.

Thus the relation between the diminution of the volume of a gas and the pressure that causes it, is expressed in the following law: *The volume of a gas is*

* This theory is not a modern conception. It is at least as old as the Greek philosopher Leucippus and his pupil Democritus, who lived about the middle of the fifth century B.C. It was taught by Epicurus in the third century, and made the basis of the famous philosophical poem of Lucretius, a Latin poet who lived about the middle of the first century B.C. It was, in recent times, elaborated by John Dalton, an English physicist, who published a complete statement of the theory in 1810. Its applications to mechanical and chemical philosophy, it is claimed by some, are inconsistent and irreconcilable. Thus it is remarked by Stallo that "while the absolute equality of the primordial units of mass [atoms] is an essential part of the very foundation of the mechanical theory, the whole modern science of chemistry is based on a principle directly subversive of it—a principle of which it has recently been said [by J. P. Cooke] that 'it holds the same place in chemistry that the law of gravitation does in astronomy.'" This principle is that known as the law of Avogadro, or Ampère, which asserts that "equal volumes of all substances, when in the gaseous form and under like conditions of pressure and temperature, *contain the same number of molecules.*"

inversely proportional to the pressure. That is, twice the pressure produces one-half the volume; three times the pressure, one-third of the volume.

9. **A physical theory** is a systematic exposition of a particular class of phenomena, and is based upon a consideration of all the laws relating to it.

Thus we have the theory of light, of heat, of electricity, etc. An *hypothesis* is a supposition used to explain some particular phenomenon.

10. **Physical agents** are the forces of nature acting on matter, and causing various phenomena; such as gravitation, heat, light, magnetism, and electricity.

These physical agents are discerned only by their effects; their intrinsic nature is entirely unknown. It is now a prevailing hypothesis that there is a subtile, imponderable, and elastic fluid, called *ether*, distributed throughout the universe, pervading all bodies; that the atoms of which matter is composed are capable of definite motions varying in character and velocity; that these motions can be imparted to the ether; and that they produce heat and light, according to their velocity, and, when of a peculiar character, cause electricity. Thus all physical phenomena are conceived to be but transformations of motion.*

II.—PROPERTIES OF BODIES.

11. **Properties of bodies** are the different ways in which bodies present themselves to the senses. They are either *general* or *specific.*

12. **General properties** are those that belong to all bodies. The most important are *extension, impenetrability, divisibility, porosity, compressibility, elasticity, mobility,* and *inertia.*

13. **Specific properties** are such as are observed in certain bodies only, or in certain states of those bodies: as *solidity, fluidity, tenacity, ductility, malleability, hardness, brittleness, transparency, color,* etc.

Impenetrability and extension are the only essential attributes of matter, since either is sufficient to define it. Divisibility, porosity, compressibility, and elasticity do not apply to atoms, but only to bodies.

* "The primary elements of all natural phenomena are *mass* and *motion.* Mass is indifferent to motion, which may be imparted to it, and of which it may be divested, by a transference of motion from one mass to another. Mass remains the same, whether at rest or in motion. Both mass and motion are constant. The elementary units of mass, being simple, are in all respects equal; absolutely hard and inelastic; and absolutely inert, and therefore purely passive."—*Stallo's Concepts and Theories of Modern Physics.* The word *mass* is here used to express *matter* divested of all the qualities which are conceived to arise from some form or kind of motion. The above include the fundamental propositions of what is called the *atomo-mechanical theory.*

14. **Extension** is that property of matter by virtue of which it occupies a definite portion of space.

Extension has three dimensions—length, breadth, and thickness. The quantity of space occupied by a body is its *volume*.

15. **Impenetrability** is that property of matter by virtue of which a body excludes every other body from the space which it occupies.

That is to say, two bodies, or separate portions of matter, cannot occupy the same space at the same time. Thus when a stone is dropped into a vessel of water, the water rises by an amount equal to the volume of the stone; showing that the water has not been penetrated but displaced by it. It will be found, however, by experiment, that the volume of a mixture, of water and alcohol, for example, is less than the sum of the volumes of the bodies which compose it. This is explained by the hypothesis that the molecules of one partly occupy the interstices between the molecules of the other.

If we attach a piece of paper to the inner surface of the bottom of a tumbler, and plunge the inverted tumbler into a vessel of water, on withdrawing it from the water the paper will be found unmoistened, showing that the water has not reached it, on account of the air in the tumbler; for the water can only compress the air, it cannot penetrate it.

16. **Divisibility** is that property of matter by virtue of which it is capable of being divided into parts.

The divisibility of matter, though extreme, is conceived to have a limit, because the phenomena of chemistry lead to the conclusion that every substance consists of indivisible particles, or atoms.

The extreme divisibility of matter is shown by various phenomena. The tenth part of a grain of musk will continue for years to fill a room with its odoriferous particles, with scarcely any loss of weight. The red globules of human blood are less than the 3500th part of an inch in diameter. More than a million of them are contained in a drop that might be suspended from the point of a needle. Animalculæ scarcely discernible through the microscope have blood flowing through their veins. How inconceivably minute must be the blood particles of these infinitesimal creatures!

17. **Porosity** is the property of possessing pores, or interstices between the component molecules.

Some substances are obviously full of pores: as sponge, wood, and pumice-stone. These are called *sensible pores*. Interstices so small that the surrounding molecules remain within the sphere of each other's attractions and repulsions are designated *physical pores*.

The porosity of gold was proved in 1661, by the Florentine experiment designed to test the compressibility of water. A thin hollow globe of gold being filled with water, and tightly closed, was subjected to great pressure in order to alter its form, and thus diminish its capacity. The water, however, resisted the pressure,

and forced its way through the pores of the gold, exhibiting itself in drops, like dew, on the outer surface.

18. **Compressibility** is that property of matter by virtue of which it may be diminished in volume by pressure.

Different substances vary greatly in this respect. The most compressible bodies are gases, while liquids have very little compressibility. Solids possess this property in widely different degrees.

19. **Elasticity** is that property by virtue of which a body resumes its original form or volume, when the force that has changed it ceases to act.

Gases and liquids are perfectly elastic; that is, they regain exactly their original volume after compression. Solids have widely different degrees of elasticity. India-rubber, ivory, and glass are examples of elastic bodies; while lead and clay are almost wholly inelastic.

If a ball of ivory, glass, or marble be allowed to fall upon a slab of polished marble slightly smeared with oil, it will rebound, rising to a height nearly equal to that from which it fell; and a circular blot of oil will be found upon the ball where it struck the slab, showing that it was flattened at that point, but regained its original form.

20. **Mobility** is the capability which a body possesses of being moved, or of changing its position in space.

21. **Motion** is a continued change of position in space.

A body is said to be *at rest*, when it is not in motion. A body while in motion may relatively be at rest. Thus a passenger in a railway carriage may be in a state of rest in relation to the train, while being carried along at a speed of twenty or thirty miles an hour.

22. **Inertia** is that property of matter by virtue of which it cannot of itself change its state, whether of motion or rest.*

If a body is at rest, it will remain at rest; and if in motion, it will continue to move in the same direction, and with the same velocity, until acted upon by some external force. This is the substance of Newton's first law of motion.

The inertia of matter is illustrated in various familiar phenomena. A rider is carried over the head of a horse when it suddenly stops, because he does not immediately lose the motion which he had acquired. In striking the handle of a hammer against the ground, the handle suddenly stops, but the head, striving to continue its motion, fixes itself more firmly on the handle. The application of a heavy fly-wheel to machinery to regulate its movements, depends upon inertia;

* Inertia is, in fact, not a property of matter but a law of motion. It implies not positive resistance, but mere passiveness. Motion cannot create itself, nor can it destroy itself; there must be what is called *force* to do either. The units of mass, or atoms, are conceived as absolutely passive or inert, the motion which they possess being "due to some primordial impulse."

since, when the wheel is once set in motion, it continues to revolve for some time after the force which moved it has ceased. This prevents all jerking, and produces uniformity in the motion of the machinery.

III.—FORCE, EQUILIBRIUM, AND MOTION.

23. **Force** is that which acts upon a body to cause or modify its motion, or to bring it to a state of rest when in motion.

24. **Velocity** is the rate at which a body moves. When the body passes over equal spaces in equal times, the velocity is said to be *uniform;* when this is not the case, it is *variable.*

Uniform velocity is measured by the number of units of space described in a given unit of time. The units commonly employed are feet and seconds. For example, a velocity of 5 means a velocity of five feet in a second. The following are examples of velocity thus expressed:

Snail	0.005	Carrier-pigeon	120
Military quick step	4.6	Hurricane	160
Moderate wind	10	Sound	1,090
Sailing wind	18	Cannon-ball	1,180
Steam vessel	22	Rifle-ball	1,330
Express train	45	Point on the equator (earth's rotation)	1,520
Gale	50	Earth in its orbit	100,000
Flight of an eagle	100	Light (186,000 miles)	960,000,000

25. **Uniform motion** is produced in a body when it is acted upon by a single force. The motion is then in a straight line, and is called *rectilinear motion.*

26. **Curvilinear motion** is caused when a body having been acted upon by a momentary force, is constantly deflected from its rectilinear path by a continuous force.

A force in regard to the time in which it acts, is either *momentary* or *impulsive*, or *continuous.* The former acts, and then ceases to act, as the force of explosion (cannon-ball) or impact (billiard-ball); the latter acts constantly, as gravitation and magnetic attraction. If the strength of a continuous force does not vary, it is called a *constant force.*

27. **Momentum** is the quantity of motion in a body at any particular time. It varies directly as the mass, or quantity of matter, and the velocity jointly.

Hence, to express the momentum of a body numerically, the number of units of mass must be multiplied by the number of units of velocity. Thus, the momentum of a body weighing five pounds [unit of mass, 1 lb.], and moving at the rate of twelve feet a second [unit of velocity, 1 foot], would be expressed by 60 (5×12); and another weighing three pounds, and moving at the rate of ten feet a second, would have a momentum of 30. Hence the momentum of the first would be twice as great as that of the second.

28. **Measure of Force.**—Force, when constant, is measured by the momentum which it communicates to a body in a given unit of time. If variable, it is measured, at any instant, by the momentum which it would communicate if it remained constant for a given unit of time from that instant.

In the British system of weights and measures, the *unit of force* is that force which, acting on a pound of matter, would produce a velocity of one foot a second. This unit is called a *poundal*.

29. **Weight** is caused by the force of gravity, or the attraction of the earth.

As the earth is not a perfect sphere, all parts of its surface are not at the same distance from the center; and as the attraction varies with the distance, the weight of a body is not the same at different parts of the earth. This may be verified by attaching a piece of metal to a delicate spring, and noting the variations in the length of the spring during a voyage from a place in the northern hemisphere to one in the southern hemisphere—say, from London to the Cape of Good Hope.

Hence to the *poundal* as a unit of weight or force, must be attached, as a condition, the latitude of the place in which it is used.

30. **Representation of Forces.**—Since a single force acting on a body produces rectilinear motion, the direction of a force and its quantity for any particular time may be represented by a straight line.

In the straight line A B (Fig. 1), let O represent the point at which a force begins to act (called the *point of application*), its line of action being either toward A or B. The direction of the force will be either O A or O B. Let us suppose the force which acts along O A to contain a certain number of units; then from O toward A, measure off O N, containing the same number of units of length, and the line O N will represent the force. O M, being equal to O N, contains the same number of units of length, and represents an equal force, but acting in the opposite direction. This difference in direction is usually represented by the signs + and −, that toward A being positive, and that toward B negative.

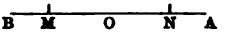


Fig. 1.

31. The **resultant** of two or more forces acting together is that force the effect of which is the same as the combined effects of the different forces. The separate forces are called *components*.

If there are two forces acting at O (Fig. 1) in the same direction along the line toward A or B, they will be equivalent to a single force containing as many units as both the forces together; but if the forces act in opposite directions, one toward A and the other toward B, they will be equivalent to a force containing the difference of their units, which will act in the direction of the greater force.

Thus, if a force of 5 units act at O toward A, and one of 8 units act at O toward B, the resultant will be a force of 3 units acting toward B. If the forces are equal and in opposite directions, the resultant is zero, and the body remains at rest.

32. **Resultant of Two or more Forces.**—When a body moves from rest under the action of any number of forces, its motion is in the direction of their resultant. When two equal forces act upon a body in different, not opposite, directions, it moves in a straight line between them.

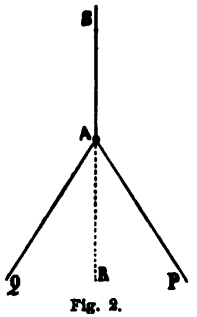


Fig. 2.

Thus let the body A (Fig. 2) be acted upon simultaneously by the equal forces P and Q, and the resultant will be R, causing it to move between the directions of the separate forces. If at the same time a force S, equal to R, act upon the body in the direction A S, the body will remain at rest, as the forces are equal and in opposite directions.

33. **Parallelogram of Forces.**—When two forces act upon a body in different directions, the resultant may be represented by the diagonal of a parallelogram of which any two adjacent sides represent the magnitude and direction of the separate forces. This is called the *parallelogram of forces.*

Thus let P and Q (Fig. 3) represent two forces acting at the point A along A P and A Q, respectively, and let A B and A C each contain a certain number of

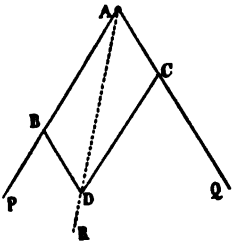


Fig. 3.

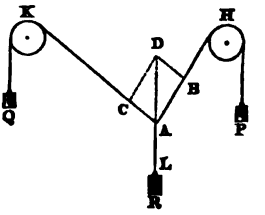


Fig. 4.

units of length, equal to the number of units of force in P and Q respectively. Then at B and C draw the lines B D and C D, respectively parallel to A Q and A P, thus completing the parallelogram A B D C. Then the body will move over the diagonal A D in the same time that it would have moved over A B or A C under the influence of the forces acting separately, and A R is the resultant of the two forces.

Experimental Proof.—Suppose H and K (Fig. 4) to be two pulleys with axles made as smooth and fine as possible. Let P and Q be two weights sus-

pended from fine and flexible threads, which, after passing over H and K, are fastened at A to a third thread A L, from which hangs a weight R. Let the three weights come to rest in the positions shown in the figure. Now the point A represents a body acted upon by three forces in equilibrium, namely, P, from A to H; Q, from A to K; and R, from A to L. Consequently, any one of them must be equal and opposite to the resultant of the other two. If now we measure off along A H the part A B, containing as many inches as P contains pounds, and along A K the part A C, containing as many inches as Q contains pounds, and complete the parallelogram A B C D, it will be found that the diagonal A D is in the line A L, and contains as many inches as R weighs pounds. Consequently, the resultant of P and Q is represented by A D.

34. **Resultant of Several Forces.**—By the principle of the parallelogram of forces, the resultant of any number of forces can be found by first finding the resultant of two, then of that and a third force, and so on.

Thus let a body at A (Fig. 5) be acted upon by the forces P, Q, R, and S, and let them be represented by the lines A B, A C, A D, A E. First complete the parallelogram A B F C, and draw the diagonal A F, which will represent the resultant of P and Q. Then complete the parallelogram A F G D, and draw the diagonal A G, which will represent the resultant of P, Q, and R; and proceed in the same manner with the other force, when it will be found that A H is the resultant of the whole.

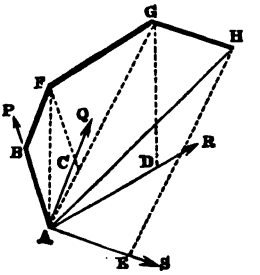


Fig. 5.

35. **Action and reaction** are always equal and in opposite directions.

In other words, the actions of two bodies on each other are always forces equal in amount and opposite in direction. This is a general law, and is equally true when the bodies are in motion and when they are at rest. The illustrations of its operation are numberless. In flying, the reaction of the air struck downward by the wings causes the bird to move upward; a person in a boat pushes against the bank with an oar, and the reaction sends the boat in the opposite direction. The reaction of the ground causes the ball to rebound when it is thrown down. We could not walk but for the reaction of the ground on which we tread.

IV.—SIMPLE MACHINES.

36. There are six simple contrivances by means of which a certain amount of power can be so applied as to move a much greater weight. These are simple machines, sometimes called *mechanical powers*.

Thus, if a force of 5 units act at O toward A, and one of 8 units act at O toward B, the resultant will be a force of 3 units acting toward B. If the forces are equal and in opposite directions, the resultant is zero, and the body remains at rest.

31. Resultant of Two or more Forces.—When a body moves from rest under the action of any number of forces, its motion is in the direction of their resultant. When two equal forces act upon a body in different, not opposite, directions, it moves in a straight line between them.



Thus let the body A (Fig. 3) be acted upon simultaneously by the equal forces P and Q, and the resultant will be R, causing it to move between the directions of the separate forces. If at the same time a force S, equal to R, act upon the body in the direction A S, the body will remain at rest, as the forces are equal and in opposite directions.

32. Parallelogram of Forces.—When two forces act upon a body in different directions, the resultant may be represented by the diagonal of a parallelogram, of which any two adjacent sides represent the magnitude and direction of the separate forces. This is called the *parallelogram of forces*.

Thus let P and Q (Fig. 4) represent two forces acting at the point A along A P and A Q, respectively, and let A B and A C each contain a certain number of



Fig. 4.

units of length, equal to the number of units of force in P and Q respectively. Then, if lines be drawn from B and C, respectively parallel to A Q and A P, the opposite parallelogram A B D C. Then the body will move over the diagonal A D in the same time that it would have moved over A B or A C under the influence of the forces acting separately, and A R is the resultant of the two forces.

Experiment. Proof.—Suppose D and E (Fig. 4 a) to be two pulleys with cords and weights, and the cords passing. Let P and Q be two weights sus-

pended from fine and flexible threads, which, after passing over H and K, are fastened at A to a third thread A L, from which hangs a weight R. Let the three weights come to rest in the positions shown in the figure. Now the point A represents a body acted upon by three forces in equilibrium, namely, P, from A to H; Q, from A to K; and R, from A to L. Consequently, any one of them must be equal and opposite to the resultant of the other two. If now we measure off along A H the part A B, containing as many inches as P contains pounds, and along A K the part A C, containing as many inches as Q contains pounds, and complete the parallelogram A B C D, it will be found that the diagonal A D is in the line A L, and contains as many inches as R weighs pounds. Consequently, the resultant of P and Q is represented by A D.

34. **Resultant of Several Forces.**—By the principle of the parallelogram of forces, the resultant of any number of forces can be found by first finding the resultant of two, then of that and a third force, and so on.

Thus let a body at A (Fig. 5) be acted upon by the forces P, Q, R, and S, and let them be represented by the lines A B, A C, A D, A E. First complete the parallelogram A B F C, and draw the diagonal A F, which will represent the resultant of P and Q. Then complete the parallelogram A F G D, and draw the diagonal A G, which will represent the resultant of P, Q, and R; and proceed in the same manner with the other force, when it will be found that A H is the resultant of the whole.

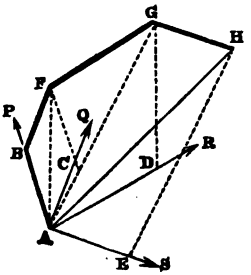


Fig. 5.

35. **Action and reaction** are always equal and in opposite directions.

In other words, the actions of two bodies on each other are always forces equal in amount and opposite in direction. This is a general law, and is equally true when the bodies are in motion and when they are at rest. The illustrations of its operation are numberless. In flying, the reaction of the air struck downward by the wings causes the bird to move upward; a person in a boat pushes against the bank with an oar, and the reaction sends the boat in the opposite direction. The reaction of the ground causes the ball to rebound when it is thrown down. We could not walk but for the reaction of the ground on which we tread.

IV.—SIMPLE MACHINES.

36. There are six simple contrivances by means of which a certain amount of power can be so applied as to move a much greater weight. These are simple machines, sometimes called *mechanical powers*.

A machine is any contrivance by means of which power can be applied to overcome resistance more advantageously than otherwise. Though the power is usually less than the resistance, or weight, the *work* applied to the machine is equal to that accomplished by it. If a power of 10 pounds is made, through the intervention of a machine, to move 100 pounds, it nevertheless does a work equal to the 100 pounds, for it must be applied ten times as long, or must be repeated ten times. A man who can carry only 50 pounds can nevertheless transport a ton of coal of 2,000 pounds; but he must repeat his application of 50 pounds forty times, in carrying successive loads; and hence does a work equal to the resistance. A machine, therefore, does not create energy, it only enables us to apply it conveniently.

The momentum of the power must be equal to that of the weight, in order to move it; but momentum depends upon quantity of matter and velocity; hence a power of 10 pounds can be made to move a weight of 100 pounds by making its velocity ten times as great. The general law is: *the power multiplied by its velocity is equal to the weight multiplied by its velocity.*

37. The six simple machines are the **lever**, the **pulley**, the **wheel and axle**, the **inclined plane**, the **wedge**, and the **screw.**

38. The **lever** is an inflexible bar, straight or curved, resting on a fixed point or edge, called the *fulcrum*.

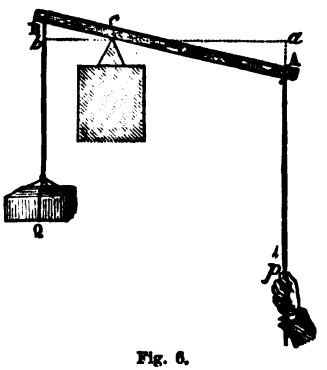


Fig. 6.

The forces acting on the lever are the *weight*, or resistance, Q (Fig. 6), the *power* P, and the reaction of the fulcrum. Since these balance each other, the resultant of P and Q must act through *C*. Ac and Bc are called the *arms of the lever*. When the lever moves on the fulcrum, the velocities of the power and weight depend on their respective arms; for Aa has the same ratio to Bb as Ac has to Bc; that is, if the arm Ac is twice as long as the arm Bc, the distance (Aa) through which the power moves must be twice as great as the distance (Bb) through which the weight moves *in the same time.* Hence the velocity is twice as great. Therefore, in the lever, *the power is to the weight in the inverse ratio of their arms; i.e.*, the longer the arm Ac, the less the power, and the shorter the arm Bc, the greater the weight.

39. **Levers** are divided into three kinds, according to the position of the fulcrum with respect to the positions of the power and the weight.

40. A **lever of the first kind** is one in which the fulcrum is between the power and the resistance, or weight.

A lever of this kind is represented in Fig. 6. The common steelyard is an

example; also the balance, having equal arms, and the handle of a pump. A pair of scissors and a carpenter's pincers are double levers of this kind.

41. A **lever of the second kind** is one in which the resistance, or weight, is between the power and the fulcrum.

Of this a wheelbarrow, a pair of nut-crackers, and a door are familiar examples; also the oar used in rowing a boat, the fulcrum being in the water, the resistance at the thole, and the power at the end held by the oarsman.

42. A **lever of the third kind** is one in which the power is between the fulcrum and the resistance, or weight.

In this, as the arm to which the weight is attached is longer than that to which the power is applied, the power must be proportionally greater than the weight. This lever is useful, not in aiding to overcome resistance, but in giving ease and agility to the movements of a body; as in the forearm, in which the weight is at the hand, the fulcrum at the elbow, and the power at the muscles between them. The treadle of a lathe or a sewing-machine is another instance of its application.

43. A **compound lever** is a combination of levers so arranged that the shorter arm of one may act on the longer arm of another, and so on to the end of the series.

44. The **pulley** is a hard circular disc of wood or metal, in the edge of which is a groove, and which is made to turn freely on an axis in the center. Pulleys are either *fixed* or *movable*.

45. A **fixed pulley** is one in which the stirrup, or block, is rigidly connected with some immovable body, the axis of the grooved wheel, or *sheave*, rotating in the block, or stirrup.

Such a pulley is seen in Fig. 7. The rope which passes round the wheel supports a weight Q at one end, and the power is applied at the other. As the power moves no faster than the weight in this case, they must be equal, the only mechanical advantage being a change in the direction of motion, for it is usually easier to pull downward than to lift upward. The fixed pulley corresponds to a lever of the first kind, the fulcrum being at the axis.

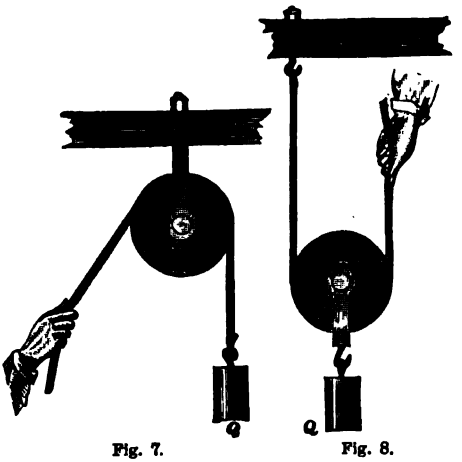


Fig. 7. Fig. 8.

46. **A movable pulley** is one in which the weight is attached to the pulley and moves with it.

This is represented in Fig. 8. One end of the rope is suspended to a fixed point, and the weight Q is attached to the hook on which the pulley acts. This corresponds to a lever of the second kind, the fulcrum being at the fixed point, or at the extremity of the diameter of the wheel where the cord touches the circumference, the power acting at the other extremity, and the weight at the center. Hence the arm of the latter is twice that of the former, and therefore the power must be one-half the weight. One-half the weight is supported by the fixed point, and the other half by the power. The weight rises through a distance equal to one-half the length of the cord drawn out by the power.

47. When several pulleys are joined together on a common axis in a special sheath, which is fixed, and a rope passes round all those, and also round a similar combination of movable pulleys, this is called a **block and tackle.**

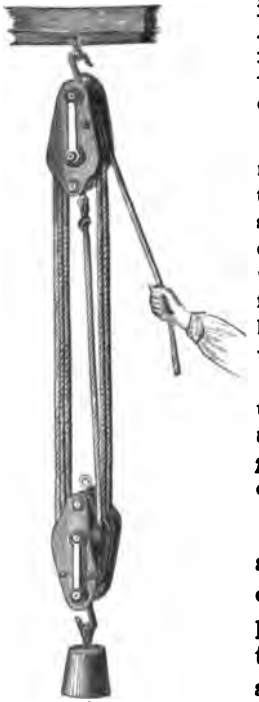


Fig. 9.

Such a combination of three movable pulleys is represented in Fig. 9. The weight Q, which is attached to the hook common to the whole system, is supported by the six portions of the rope. Hence each of these portions will sustain one-sixth of the weight; and, consequently, the power applied at the free end of the rope which passes over the upper pulley will support one-sixth of the weight. Hence the weight may be six times as great as the power.

Other combinations of movable pulleys may be used, and the general law is that the *weight is equal to the power multiplied by twice the number of movable pulleys.* Hence with five movable pulleys a power of one pound will move a weight of ten pounds.

48. The **wheel and axle** consist of a larger and a smaller wheel firmly attached to each other, and moving on a common axis, the power being applied to the circumference of the larger wheel to overcome the resistance acting at the circumference of the smaller one (axle).

Thus the power P (Fig. 10) acts at the circumference of the large wheel at *c* to overcome the resistance of the weight Q, acting at *b*, both wheels moving round the common axis *a*. It will be obvious that this is equivalent to a lever of the second kind, the fulcrum being at the axis, and the arms being the radii

of the two wheels. The relation of the power to the weight must therefore depend on the relative lengths of these radii, or the circumferences, which have the same ratio. Thus if the radius of the wheel is five times as long as that of the axle, a power of one pound will move a weight of five pounds. The windlass and the capstan are examples of this contrivance.

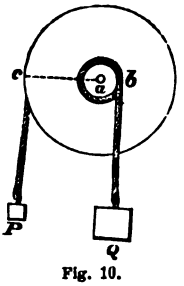


Fig. 10.



Fig. 11.

Frequent applications of wheels of different diameters are met with in which the motion of one wheel is transmitted to another, either by means of teeth, as in Fig. 11, or by bands passing over the two wheels. In the figure the power P moves the small-toothed wheel c, which turns the large-toothed wheel a, and moves the weight Q, acting on the small wheel, or axle, b. There being ten teeth in the wheel c, and forty in a, the former will perform four rotations to one of the latter.

Trains of wheelwork are used not only in raising great weights by the exertion of a small power, as in screw-jacks, cranes, etc., but in clock and watch work, and in all cases requiring a change in power, velocity, or direction of motion.

49. Inclined Plane.—This is, as the name implies, merely a plane surface at any angle to the horizon.

The properties and laws of the inclined plane may be conveniently demonstrated by means of the apparatus represented in Fig. 12. R S represents a smooth piece of hard wood hinged at R, so that it may be raised to any angle x, measured by the scale. To the roller a is attached a string which passes over a pulley to the scale-pan P. The line R S represents the *length*, S T the *height*, and R T the *base* of the inclined plane. The power in this case acts, as usually, in a direction parallel to the plane, and passes over the whole length in order to lift the weight the distance S T. Hence the ratio of the weight to the power must be equal to that of the *length* to the *height*.

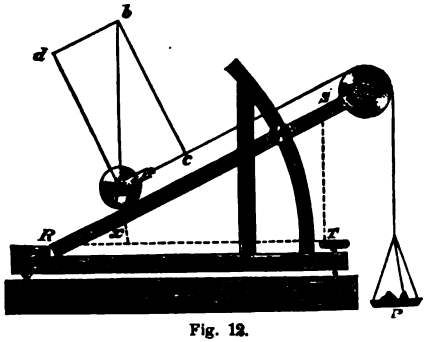


Fig. 12.

In illustrating this, we may apply the parallelogram of forces. Thus let $a\ b$ represent the vertical force of the weight. This can be resolved into two forces, one $a\ d$, acting perpendicularly to the plane, the other $d\ b$, or its equal $a\ c$, acting parallel to it. The former is counteracted by the reaction of the plane; the latter represents the tendency downward that has to be counteracted by the power.

Hence $a\,b$ represents the weight, and $a\,c$ the power; and it can be proved that the ratio of $a\,b$ to $a\,c$ is the same as R S to S T; that is, as the length to the height.

In most cases of the use of the inclined plane, such as in moving carriages and wagons along roads, in raising casks into wagons or warehouses, the power is applied in a direction parallel to the plane. If applied at an angle with it, the force would consist of two forces, of which the one parallel with the plane would alone be operative.

50. **Wedge.**—The form of the wedge is that of two inclined planes placed base to base. Its most frequent use is in lifting timber, stone, etc. Axes, nails, knives, etc., are constructed on the principle of the wedge.

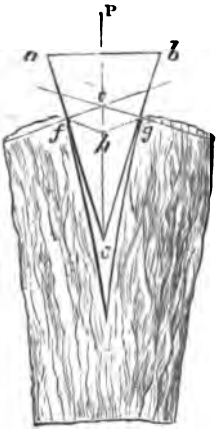


Fig. 13.

The use of the wedge is represented in Fig. 13. The line $a\,b$ represents the *back* of the wedge, the angle $a\,c\,b$ the *edge*, and the faces $a\,c$ and $b\,c$ the *sides*. The power P is usually applied at right angles to the back; and we may consider the cohesion between the fibres of the wood as the resistance to be overcome, or the weight. The same law applies to the wedge as to the inclined plane: the ratio of the power to the weight is equal to that of the back of the wedge to the length of either of its sides. Hence the sharper the wedge, the more effective is its action. It is very useful when very heavy weights are to be raised through a short distance, as in launching ships and bracing columns and walls to the perpendicular.

51. The **screw** may be conceived as an inclined plane wound around a cylinder, the length of the plane forming the *thread*, and

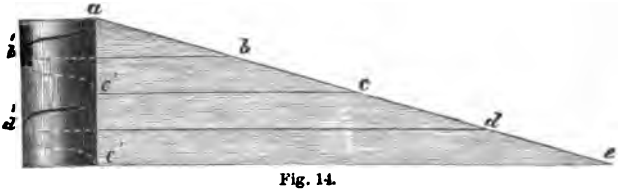


Fig. 14.

the cylinder being the *body*. The hollow cylinder, supplied with reverse threads, in which the screw works, is called the *nut*.

This relation of the screw and inclined plane will be rendered obvious by Fig. 14. If a triangular piece of paper, $a\,e\,e'$, be wrapped around the cylinder, the circumference of the base of which is equal to the length of the base $e\,e'$ of the triangle, a screw line will be formed, the points b, c, and d of the inclined plane

corresponding to b', c', and d' of the screw. Figs. 15 and 16 represent the screw and the nut.

In the use of the screw, it is obvious that the power applied must perform one revolution in order that the screw may be moved a distance equal to that between any two of the threads. A lever is usually employed in connection with the power. Hence, the ratio of the weight to the power is equal to that between the circumference of the circle in which the power moves and the distance between the threads. Therefore, the longer the lever applied to the power, and the finer the threads of the screw, the greater the advantage gained by its use.



Fig. 15.



Fig. 16.

52. **Friction.**—The surfaces of bodies in contact are never perfectly smooth. Even the smoothest present inequalities which are insensible to both sight and touch. Hence, when one body moves over the surface of another, the elevations of one sink into the depressions of the other, like the teeth of wheels, and thus offer a resistance to motion. This resistance is called *friction.*

53. Friction is of two kinds: **sliding friction,** as when one body glides over another; and **rolling friction,** as when one body rolls over another, of which the ordinary wheel is an example.

Friction is directly proportional to the pressure of the two surfaces against each other; and, the pressure being the same, is independent of the extent of the surfaces in contact. It is diminished by polishing and smearing, but is increased by heat. As rolling friction is considerably less than sliding friction, it is a great saving of power to substitute the former for the latter; as is done in the casters of chairs and other articles of furniture. Sometimes it is necessary to change rolling into sliding friction, as when drags are placed on carriage wheels.

Without friction on the ground we could not walk or run, nor could railway cars or any other vehicles be moved. Friction is necessary for the transmission of power from one wheel to another by means of bands or ropes, and without it we could hold nothing in our hands.

V.—MOTION.

54. **Rectilinear Motion.**—A body acted upon by a single impulsive force moves with a uniform rectilinear motion until stopped by some other force (Art. 25). When acted upon by a continuous force, such as gravity, it moves in a straight line with a *uniformly accelerated motion.*

Thus in Fig. 17, let the line A C represent equal intervals of time, A D, D E, E F, etc.; and let P D, Q E, R F, etc., represent the velocities acquired by a

moving body at the end of each; then the triangles A P D, A Q E, A R F, etc., will represent the spaces described in different portions of time. Since Q E is equal to 2 P D, R F to 3 P D, etc., the *velocities are in proportion to the times;* and since A Q E is equal to 4 A P D, A R F equal to 9 A P D, A S G equal to 16 A P D, *the spaces described are in proportion to the squares of the times*, or to the squares of the velocities acquired. And the spaces described in equal successive periods of time are in proportion to the odd numbers 1, 3, 5, 7, etc., increasing by a constant quantity; while the velocities acquired at the end of each second are as the numbers 1, 2, 4, 6, 8, etc., being in proportion to the times.

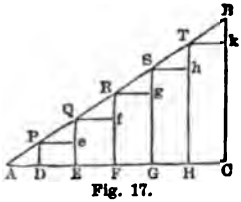


Fig. 17.

55. **Motion in a Circle.**—A body moving in a circle must be acted upon by two forces, one drawing it to the center, called the *centripetal force;* and the other, that by which it tends to move in a straight line from the center, called the *centrifugal force.*

When a stone is whirled around in a sling, the cord that holds it to the center of motion represents the centripetal force; and if the cord breaks, that force being suspended, the stone immediately moves in a straight line away from the center; and this straight line is a tangent to the circle in which the body was moving.

The motions of the heavenly bodies in their orbits illustrate this principle. Thus suppose a body moving in a circle to be at the point *a* (Fig. 18); and that, if acted upon by only one force, it would, in a certain interval of time, pass over the straight line *a b*; while the centripetal force in the same time would bring it to *c*, in the direction *a c*. If these forces were both impulsive forces, it would pass over the diagonal *a d*; but as the centripetal is a continuous force, deflecting it from the straight line *at every point*, it describes the curve *ad*, and so on throughout the circle. But if the centripetal force should cease, it would immediately resume its rectilinear motion in a tangent, like *ab*.

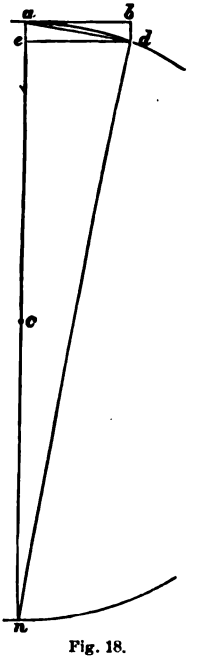


Fig. 18.

The operation of the centrifugal force may be illustrated by means of numerous familiar experiments. If a pail of water be suspended and caused to rotate, the water will overflow. Large wheels and grindstones, when revolving very rapidly, often break, the pieces flying off with great force and velocity. Where railways make a short curve, the outer rail is laid higher than the inner, for the purpose of counteracting the centrifugal force.

VI.—THE PENDULUM.

56. A **simple pendulum** consists of a heavy particle suspended by a fine thread from a fixed point, about which it oscillates without friction.

The oscillation, or vibration, of the pendulum is caused by gravity and inertia, the former bringing it to the vertical position, and the latter causing it to pass beyond that position.

The simple pendulum has only an imaginary existence; the common pendulum consisting of a suspended weight is called a *compound pendulum*. The several material points of such a pendulum tend to perform their oscillations in different times, as they are at different distances from the axis of suspension. The length of a compound pendulum is that of a simple pendulum which would describe its oscillations in the same time.

57. The **center of suspension** is that point of the axis which, when the pendulum is at rest, is vertically over the center of gravity of the body. (See Art. 72.)

58. The **center of oscillation** is that point at which the pendulum vibrates as if its whole mass were collected there.

This point is farther from the center of suspension than the center of gravity, being below it. If a pendulum be inverted and suspended at a point at which it will vibrate in the same time as before, that point of suspension would be the former center of oscillation, and *vice versa*, the two centers being interchangeable. This was discovered by Huygens. The real length of a compound pendulum is, as will be obvious, the distance between the centers of suspension and oscillation.

59. The time of vibration of a pendulum is directly proportional to the square root of its length.

Or, differently stated, the lengths of pendulums are in proportion to the squares of their times of vibration. That is to say, a pendulum of a certain length that will vibrate seconds, if one-fourth that length would vibrate half seconds.

As the force of gravity differs at different parts of the earth's surface (Art. 29), the vibrations of the pendulum vary, and thus they become a measure of the force of gravity, and in this way a means of determining the figure of the earth.

It has been found that 39.13983 inches is the length of a simple pendulum whose time of oscillation at Greenwich is one second.

Application of the Pendulum.—On account of the equality of the vibrations of the pendulum it is used to regulate clocks. The manner of using it for this purpose is shown in Fig. 19. The pendulum rod passing between the prongs

of a fork *a*, communicates its motion to a rod *b*, which oscillates on a horizontal axis *o*. To this axis is fixed a piece *m n*, called an *escapement*, having two projections (*pallets*), which work alternately with the teeth of the *escapement wheel k*. In this manner the descent of the weight is alternately arrested and permitted, that is, *regulated*, by the pendulum; and by shortening or lengthening the pendulum, so as to hasten or retard its vibrations, the clock is made to go faster or more slowly.

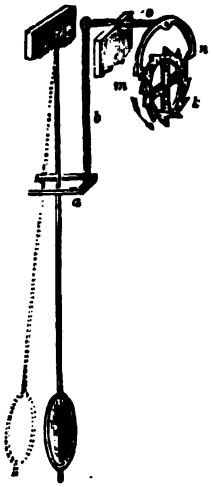


Fig. 19.

VII.—IMPULSIVE FORCES.

60. An **impulsive force** (Art. 26) is called into play when one body strikes against another; and it follows from the law of the equality of action and reaction (Art. 35) that whatever force the first body exerts upon the second, the second will exert an equal force upon the first in the opposite direction.

A force is in proportion to the momentum which it produces; hence equal forces produce equal momenta. Thus if two balls A and B (Fig. 20) be suspended from C and D, in the same horizontal line, by threads, in such a manner that their centers may be in the same horizontal line; and if it be moved back to R and then allowed to fall against B, the former will move in the curve E A F, and the latter in G B H; the one, we will say, moving to *r*, and the other to *k*, from which data Newton demonstrated experimentally that the sum of the momenta of the two bodies is the same during the whole or any part of the time of impact.

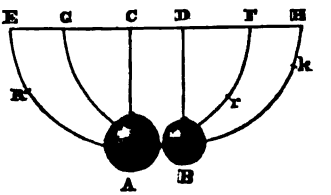


Fig. 20.

61. When two equal bodies, moving with the same velocity in opposite directions, come in contact, the force of the shock is equal to that which either would sustain while at rest, if struck by the other body moving with double the velocity.

The effect of collision upon elastic and inelastic bodies is different, but the law of momentum holds good. If two inelastic bodies, as of clay, putty, or lead, be suspended by threads, and one of them be allowed to fall against the other at rest, a part of the motion of the first ball will be communicated to the second, and both, after collision, will move on together, the quantity of motion (momentum) remaining the same.

If a similar experiment be made with two elastic bodies, as of ivory, the moving body will communicate its motion to the other, and the first will remain

at rest, while the second will move forward with the momentum which the first ball had at the time of impact.

And if a number of elastic balls of equal size be suspended side by side in contact one with another, and one of them be allowed to strike against that next to it, its motion will be communicated instantly to each ball in succession, and the last will move forward with the momentum of the first ball at the time of impact. These statements presuppose the perfect elasticity of the balls.

VIII.—WORK AND ENERGY.

62. **Work,** in physical science, is the overcoming of resistance of any kind, either by causing or changing motion, or maintaining it against the action of some other force.

A body at rest resists by its inertia a change of state; a body in motion resists the action of any force that tends to cause it to move with greater velocity, or in any other than a straight line. Any force that overcomes this resistance does work.

This use of the term is in accord with its familiar application. The mechanic and the laborer perform work only in overcoming resistance of various kinds, and in various ways, and with a greater or less degree of trained skill. The horse that draws a vehicle or carries its rider, and the steam-engine that drags a railway train or drives machinery, do work in this sense.

63. **Measure of Work.**—The quantity of work performed is measured by the amount of resistance overcome, which depends upon the two elements of weight and height.

To carry 100 bricks up to a scaffold 50 feet high requires twice as much work as to carry the same number 25 feet high, and four times as much work as to carry 50 bricks one-half the height.

The idea of *time* does not enter into the conception of work. We do not ask how long the laborer has been at work, but how much work he has done—how many bricks, for example, he has carried to a particular height.

64. The **unit of work** is the amount of force required to lift one pound to the height of one foot against the force of gravity. This is called a *foot-pound.*

This is not an absolutely invariable standard, since the weight of a pound differs somewhat at different places. The French unit of work is the weight of a kilogramme raised to the height of a metre, and is equal to 7.24 English foot-pounds.

65. **Energy** is the power of doing work.

For example, in the case of the inclined plane, the energy of the power P (Fig. 12) is represented by P × R S, and it confers upon the weight W a quantity of energy equal to that expended, since the latter is raised through a vertical

height equal to S T, and could, by falling through the same distance, do the work represented by W × S T, which is equal to P × R S.

66. The term *work* is sometimes used in a more extensive sense to signify the production of any kind of physical change.

Thus work is said to be done when a body at a low temperature is raised to a higher temperature, in the same manner as when a weight is raised from a low to a higher level. Or, again, work is done when any electrical, magnetic, or chemical change is effected. Hence energy might also be defined to be the *power to produce any physical change.*

67. **Transformation of Energy.**—When one kind of energy is expended, it gives place to another kind.

This may be illustrated by the movements of the pendulum. In passing from the position of rest to the extreme limit of its oscillation, it expends the energy communicated to it; but it then possesses, by virtue of its position, a sufficient amount of energy to bring it again to the perpendicular, the work it performs being equal to its weight multiplied by the height through which it falls. Then it possesses an energy, by virtue of its acquired velocity, sufficient to carry it to the other limit of oscillation; and thus these transformations of energy continually take place in succession.

These transformations always take place according to fixed proportions. For instance, when coal or any other combustible is burned, its chemical energy, or power of combining with oxygen, vanishes, and heat, or thermal energy, is produced; and the quantity of heat produced by the combustion of a given amount of coal is fixed and invariable.

68. **Conservation of Energy.**—As long as any system of bodies is not acted on from without, the total quantity of heat that can be obtained from it is unalterable by any changes which may go on within the system itself.

For instance, a quantity of air compressed into the reservoir of an air-gun possesses energy which is represented partly by the heat which gives to it its actual temperature above the absolute zero, and partly by the work which the air can do in expanding. When the air propels the bullet from the gun, the heat produced is partly represented by the energy of the moving bullet; and this heat reappears in the friction of the bullet against the air, and by its striking against an obstacle that stops its motion. Whatever the mode in which the energy of the compressed air is converted into heat, the total quantity remains the same.

Thus the conservation of energy is equivalent to the conservation of motion, since heat, as will be shown further on, is conceived to be only "a mode of motion."

SYNOPSIS FOR REVIEW.

MATTER, FORCE, AND MOTION.

I.—GENERAL PRINCIPLES:

1. *Physics*—Physical phenomena: { 1. Chemical. 2. Mechanical.
2. *Matter*—
 1. Atoms and molecules.
 2. States of aggregation: { 1. Solids. 2. Liquids. 3. Gases.
3. *Definitions:* { 1. Physical law. 2. Physical theory. 3. Physical agents.

II.—PROPERTIES OF BODIES:

1. *General Properties:* { 1. Extension. 2. Impenetrability. 3. Divisibility. 4. Porosity. 5. Comprehensibility. 6. Elasticity. 7. Mobility. 8. Inertia.
2. *Specific Properties.*

III.—FORCE, EQUILIBRIUM, AND MOTION:

1. *Force:* 1. Momentary, or impulsive. 2. Continuous.
2. *Velocity:* 1. Uniform. 2. Variable.
3. *Uniform Motion:* 1. Rectilinear. 2. Curvilinear.
4. *Momentum.* 5. *Measure of Force.* 6. *Weight.*
7. *Resultant:* 1. Of one force. 2. Of two or more forces.
8. *Action and Reaction.*

IV.—SIMPLE MACHINES, OR MECHANICAL POWERS:

1. *General Law of.*
2. *Description of*—
 1. Lever: 1. First kind. 2. Second kind. 3. Third kind.
 2. Pulley: 1. Fixed. 2. Movable.
 3. Wheel and axle.
 4. Inclined plane. 5. Wedge. 6. Screw.
3. *Friction:* 1. Sliding. 2. Rolling.

V.—MOTION:

1. *Rectilinear.*
2. *Uniformly Accelerated*—Law of.
3. *In a Circle.* Centripetal and centrifugal forces.

VI.—PENDULUM:

1. *Definition and Description:* { 1. Simple pendulum. 2. Compound pendulum.
2. *Centers of Suspension and Oscillation.*
3. *Law of Vibration.*
4. *Application.*

VII.—IMPULSIVE FORCES:

1. *Definition.*
2. *Law of Action.*
3. *Effect of Collision:* { 1. Of two elastic bodies. 2. Of several elastic bodies.

VIII.—WORK AND ENERGY:

1. *Work:* 1. Measure of. 2. Unit of.
2. *Energy:* 1. Transformation of. 2. Conservation of.

APPLICATION OF PRINCIPLES.

I. *Are the following mechanical or chemical phenomena?* 1. The conversion of water into steam? 2. The melting of ice? 3. The dissolving of sugar in water? 4. The burning of wood? 5. The rising of smoke in the air? 6. The rusting of iron? 7. The falling of snow? 8. The boiling of water?

II. *What prominent general property or properties has*—1. Sponge? 2. Lead? 3. Steel? 4. Air? 5. Water? 6. India-rubber? 7. Gold? 8. Ivory?

III. *Explain*—1. The difference between a solid and a liquid. 2. The difference between a liquid and a gas. 3. The rising of water in a vessel when a solid body is immersed in it. 4. Why the volume of a mixture of alcohol and water is less than the sum of the volumes of the alcohol and the water. 5. Why water can be forced through gold. 6. Why a ball of ivory or glass rebounds when it falls upon a hard surface. 7. Why a rider is thrown over his horse's head when the horse suddenly stops. 8. Why a stone thrown obliquely in the air rises and falls in a curve. 9. Why a body weighs less at the equator than at a place nearer the poles. 10. How a bird is enabled to mount in the air, and a swan to propel itself in the water. 11. Why a boat moves in the opposite direction when the oarsman pushes against the bank with his oar. 12. How a small power can be applied so as to move a great weight. 13. Why a lever of the third kind requires a greater power than the weight. 14. What kind of lever the forearm is when lifting a weight held in the hand. 15. Of what use casters are as applied to heavy tables, etc. 16. How friction enables us to walk. 17. Why a book remains upon a sloping desk, while a pencil rolls off. 18. Why a grindstone sometimes flies into pieces. 19. Why water overflows in a rotating vessel. 20. Why a billiard-ball when striking against another sometimes stands still, while the other moves onward in the same direction. 21. Why, when a billiard-ball strikes against the cushion in one direction, it rebounds in another. 22. Why energy cannot be destroyed. 23. What causes the oscillations of a pendulum. 24. Why a marble will roll farther on a bare floor than on a carpet. 25. On what principle the pendulum is used to regulate clocks. 26. Why a body falls to the earth with its heavy side foremost. 27. Why two plumb-lines cannot be exactly parallel. 28. In what way a crowbar may be used so as to be a lever of the second kind. 29. In what way to become a lever of the third kind. 30. Why two forces are required to cause a body to move in a curve.

PROBLEMS FOR EXERCISE.

1. What is the momentum of a cannon-ball weighing 25 pounds and moving with a velocity of 350 feet a second?

2. What is the momentum of a railway train weighing 250 tons, moving at the rate of 30 miles an hour?

3. A body moving with a velocity of 250 feet a second has the same momentum as another weighing 150 pounds that is moving 300 feet a second. What is the weight of the former?

4. A boat is rowed at the rate of 3 miles an hour across a stream in which the current moves at the rate of 5 miles an hour, the head of the boat being kept directly toward the opposite bank. Represent by diagram the direction of the boat, and find how long the boat will be in crossing.

5. A body falls from the topmast of a ship 60 feet high while the ship moves forward 20 feet. Draw a diagram showing the direction in which it will fall, and find the length of the line.

6. The length of a lever is 5 feet, the weight to be moved 200 pounds, and the fulcrum is 18 inches from the weight. What power is required?

7. How long must a lever be, with one end resting on the ground as a fulcrum, in order to push forward a weight of 500 pounds, which presses against the lever six inches from the fulcrum, the moving power being equivalent to 50 pounds?

8. The circumference of a wheel is 9 feet; that of the axle 15 inches. What power acting on the wheel will move a weight of 150 pounds applied to the axle?

9. If the capstan of a ship is 9 inches in diameter, and the circle described by the handspikes 10 feet in diameter, what power is exerted in raising an anchor that weighs 3,500 pounds?

10. With a system of five movable pulleys, what power is required to move 1,000 pounds?

11. An inclined plane is 300 feet long, and its perpendicular height is 10 feet. What power acting parallel to the plane will draw 2,500 pounds?

12. A weight of 2,000 pounds is held in the middle of an inclined plane 12 feet high by a power of 150 pounds. Required the distance it has to be drawn to the top.

13. What resistance does a nut offer when placed in a pair of nut-crackers at a distance of three-fourths of an inch from the joint, if a pressure of 5 pounds applied at a distance of 4 inches from the joint is just sufficient to crack it?

14. What power is applied by means of a screw with threads one-half inch apart, if driven by a lever 4 feet in length, if it overcome a resistance of 5,000 pounds?

15. What power is required to raise a cask weighing 6 hundredweight into a cart 3 feet high along a plank 12 feet in length?

16. If a horse can move 30 hundredweight along a level road, what can it move up a road the inclination of which is 1 foot in 80 feet, the amount of friction being equal to one-tenth of the power?

17. How long must a pendulum be to vibrate once in 2 seconds? How long to vibrate once in one-fourth of a second? In $1\frac{1}{3}$ second?

18. If two pendulums are, respectively, 16 inches and 36 inches in length, how do their times of vibration compare?

19. What is the length of a pendulum that will vibrate five times in three seconds?

20. The distance between two consecutive threads of a screw being one-fourth of an inch, and the length of the lever used to turn it being 5 feet, what resistance will be overcome by a power of $2\frac{1}{4}$ pounds?

21. If one of two forces acting on a body be equal to 6 pounds, and the resultant the same, the direction of the latter being at right angles to the former, what is the magnitude of the other force, and the direction in which it acts?

22. Of a series of cog-wheels, the radii of the first wheel and axle are as 5 to 1; of the second, as 7 to 3; and of the third, as 8 to 1. What weight will be sustained at the axle of the third wheel by a power of 15 pounds applied at the circumference of the first?

23. If the strength of a man is sufficient to enable him to lift a weight of 100 pounds a perpendicular height of 4 feet, what weight can he draw up an inclined plane 12 feet long, and having a perpendicular height of 4 feet?

24. How many pulleys must be combined in order that a power of 150 pounds may overcome a resistance of 3 tons?

25. A load of 2 tons is to be moved up an inclined plane by a power of 100 pounds. What must be the ratio of its length to its perpendicular height?

CHAPTER II.

GRAVITATION AND MOLECULAR ATTRACTION.

I.—UNIVERSAL GRAVITATION, GRAVITY, AND EQUILIBRIUM.

69. **Universal gravitation** is a force by virtue of which all bodies incessantly tend to approach each other.

The attraction between any two bodies is the resultant of the attraction of all the molecules of one upon those of the other.

70. The **law of universal gravitation** may be thus stated: All bodies attract all other bodies with a force directly in proportion to their mass, or quantity of matter, and inversely as the square of their distance from one another.

To illustrate this we may take the case of two spheres, which, owing to their symmetry, attract each other as if their masses were concentrated in their centers. If, without other alteration, the mass of one sphere were doubled or tripled, the attraction would be doubled or tripled; and if one were doubled and the other tripled, the attraction would be increased six times; but if the distance were doubled or tripled, the attraction would be reduced to one-fourth or one-ninth—that is, the square of one-half or one-third.

The law of universal attraction was discovered by Sir Isaac Newton. A vague idea of the tendency of the matter of the earth and stars to a common center was entertained in ancient times by Democritus and Epicurus. Kepler assumed the existence of a mutual attraction between the sun, the earth, and the other planets; and Bacon, Galileo, and Hooke recognized the existence of universal attraction. Newton, however, was the first to establish the great law that binds the whole universe of matter together.*

* Newton did not regard the attraction of gravitation as an *essential property of matter*, but only as a *secondary phenomenon* due to an unknown cause. "The reason of these properties of gravity," he said, "I have not, as yet, been able to deduce, and I frame no hypothesis." And he also said: "It is inconceivable that inanimate brute matter should, without the mediation of something else which is not material, operate upon and affect other matter without mutual contact, as it must do, if gravitation, in the sense of Epicurus, be essential and inherent in it." All the great physicists of Newton's time, although they could not deny the truth of the law as a phenomenon, repu-

Since Newton's time the mutual attraction of bodies has been experimentally shown.*

71. **Gravity,** or terrestrial gravitation, is the tendency of every body to fall toward the center of the earth, due to the mutual attraction of the earth and body.

As bodies tend to the center of the earth, an exact perpendicular or vertical line is determined by a *plumb-line* (a line with a piece of lead (*plumbum*) attached to it).

By observations on the direction of the plumb-line when deflected from the vertical position by the attraction of some great mass of matter in the vicinity, the density of the earth has been calculated. Thus Dr. Maskelyne found the deflection caused by the mountain Schehallien, in Scotland, was about 6″: and from this computed that the mean density of the earth is about five times that of water.

72. The **center of gravity** of a body is that point about which



Fig. 21.

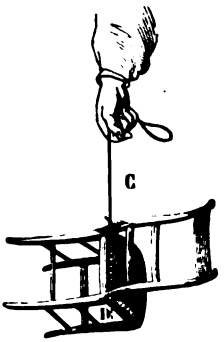


Fig. 22.

all the parts of the body balance each other, so that when that point is supported, the whole body is supported.

It is that point of a body through which the resultant of the attracting forces between the earth and its several molecules always passes.

diated it as a statement of an inherent force in matter; and distinguished modern physicists hold that "there is no other kind of force than pressure by contact of one body with another." Hence several hypotheses have been invented to account for this phenomenon of gravitation, among which is the existence of a universal fluid, to whose movements the apparent mutual attractions of bodies are due.

* "Cavendish, by means of a very sensitive torsion-balance, showed that two large spheres of lead exercised a sensible attraction upon two small spheres, and was able to measure the amount of this attraction so precisely as to deduce, from the comparison of it with the earth's attraction, that the mean specific gravity of the earth is 5.5." (See Art. 71.)

In order to determine experimentally the center of gravity of a body, suspend it by a string in two positions, as shown in Figs. 21 and 22. Now, as the body is supported in each position, the center of gravity must be in each of the lines of direction A B and C D of the string, and therefore must be at their point of intersection.

73. The **line of direction** is a vertical line that passes through the center of gravity. When this line is within the base of a body, it will be supported; but when it is without the base of the body, it will fall.

The famous leaning tower of Pisa continues to stand because the line of direction passes within its base. On this principle, it is easier for us to stand on our feet than on stilts, because, in the latter case, the slightest movement is sufficient to cause the line of direction to pass beyond the base. When standing on one foot, or in any other unusual posture, we have to move the body in such a way that the center of gravity may be supported.

74. The center of gravity constantly tends to occupy the lowest possible position; consequently, its state of equilibrium is *stable* only when the center of gravity is as near as possible to the plane on which it rests. In other positions, it is either *unstable* or *neutral*.



Fig. 23.

When a body is in a position of stable equilibrium, the slightest change in its position must elevate the center of gravity, which will descend again as soon as permitted. The pendulum continually oscillates about its position of stable equilibrium, and an egg on a level table is in this state when its long axis is horizontal. An illustration of this principle is afforded in Fig. 23. A small figure cut in ivory is made to stand on one foot at the top of a pedestal by being loaded with two leaden balls *a b*, placed sufficiently low to throw the center of gravity *g* of the whole compound body below the foot of the figure. After being disturbed the little figure oscillates like a pendulum, having its point of suspension at the toe, and its center of gravity at a lower point *g*.

75. A body is said to be in *unstable equilibrium* when, after the slightest disturbance, it tends to depart still more from its original position.

A body is in this state when its center of gravity is vertically above the point of support and higher than it would be in any adjacent position. An egg standing on its end, or a stick balanced upright on the finger, is in this state.

76. The state of equilibrium of a body is said to be *neutral* when

any change to an adjacent position neither raises nor lowers its center of gravity.

A sphere or a cylinder resting on a horizontal plane is in this state. It is the tendency of the center of gravity to descend to a lower position that causes bodies

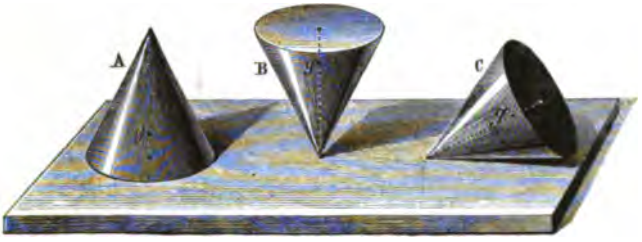


Fig. 24.

of these or similar forms to roll down an inclined plane. In Fig. 24, the three cones, A, B, C, are placed respectively in stable, unstable, and neutral equilibrium upon a horizontal plane. The letter *g* in each shows the position of the center of gravity.

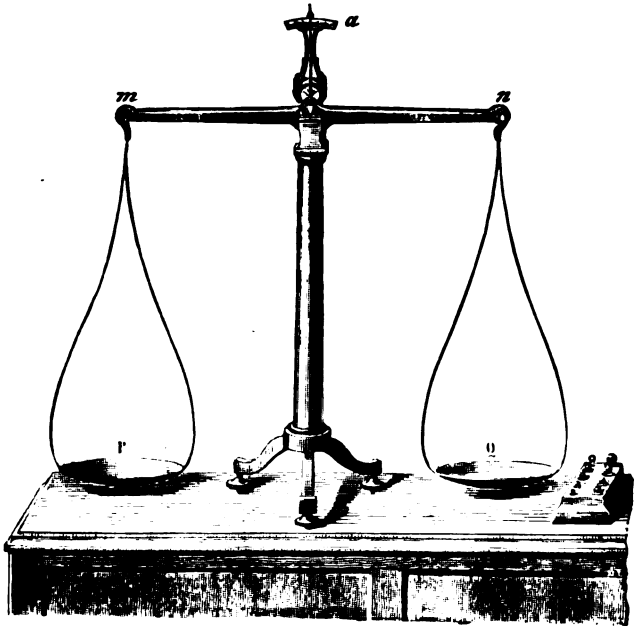


Fig. 25.

77. The balance is an instrument for determining the relative weights or masses of bodies. There are many varieties.

The ordinary balance (Fig. 25) consists of a lever of the first kind, called the beam, *m n*, with its fulcrum in the middle. At the extremities of the beam are suspended two scale-pans, P and Q, one intended to receive the object to be weighed, and the other the counterpoise. The fulcrum consists of a steel prism *o*, commonly called a *knife-edge*, which passes through the beam and rests with its sharp edge, or *axis of suspension*, upon two supports. These are formed of agate, in order to diminish the friction. A needle or pointer is fixed to the beam, and oscillates with it in front of the graduated arc *a*; and when the beam is perfectly horizontal, the needle points to the zero of the graduated arc. The scales are suspended from hooks at *m* and *n* resting on sharp edges, so that the length of the arms *n o* *m o* may remain exactly equal during the process of weighing.

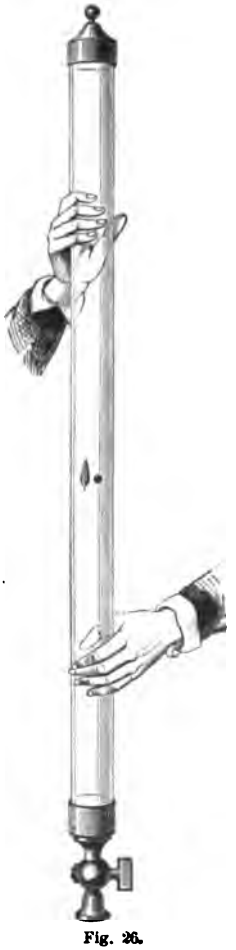


Fig. 26.

Balances are constructed with great care, and with many ingenious appliances to promote delicacy or accuracy. The sensitiveness of a balance used in chemical analysis is such that, when charged with two pounds in each scale, the fiftieth part of a grain in either scale would cause a perceptible deflection of the index.

78. Falling Bodies.—Since a body falls to the ground in consequence of the earth's attraction acting upon each of its molecules, it follows that all bodies, large and small, light and heavy, ought to fall with equal velocity. In a vacuum, or space without air, this is really the case, and a stone falls with the same rapidity as a feather.

To demonstrate this by experiment, a glass tube about two yards long (Fig. 26) is used, having one of its ends completely closed, and a brass cock fixed to the other. After placing bodies of different weights (feathers, pieces of lead, paper, etc.) into the tube it is exhausted of its air, and then the tube being reversed, the substances in it are seen to fall with equal velocity, all reaching the other end of the tube at the same time. In a vacuum liquids fall like solids, without separation of their molecules; while, ordinarily, owing to the resistance of the air, they are broken into drops.

79. As a body under the influence of gravity falls with a uniformly accelerated motion, it obeys the law already explained. (Art. 54.)

The force of gravity near the surface of the earth is such that a body falls in the first second of time through a little over 16 feet (16.08 feet). Hence in the next second it will fall through three times that space, in the third second five times the space, and so on. The spaces passed over being in proportion to the squares of the times, in two seconds the body will fall through four times 16.08 feet, in three seconds nine times, and so on.

From the principles explained in Art. 54 we deduce the following rules for solving problems pertaining to falling bodies, leaving out of consideration the resistance of the air:

Time $= \sqrt{\text{Space} \div 16.08}$.

Space = Time squared $\times$ 16.08.

Velocity = Time $\times$ 32.16.

Several instruments have been invented for illustrating and experimentally verifying the laws of falling bodies. Galileo, who discovered these laws in the early part of the seventeenth century, illustrated them by means of bodies falling down inclined planes. The great object of such instruments is to diminish the rapidity of the fall of bodies without altering the character of their motion, so that the latter may be better observed, and may be less modified by the resistance of the air.

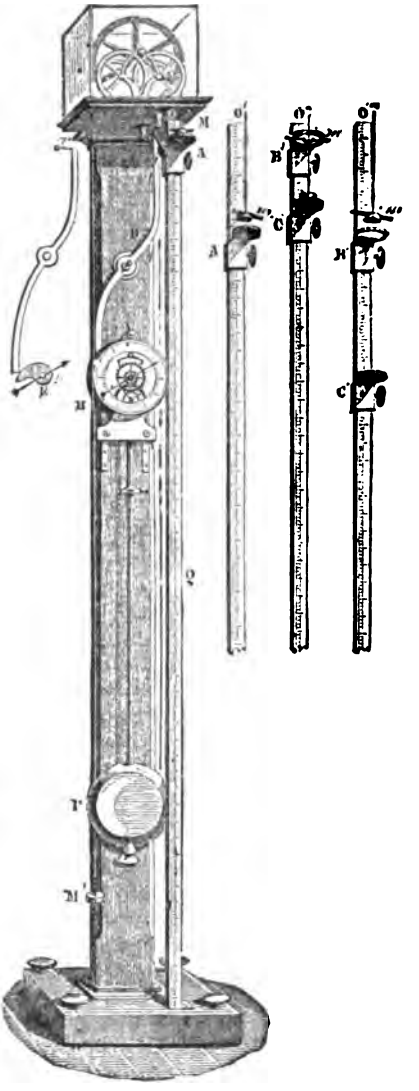


Fig. 27.

Atwood's machine, represented in Fig. 27, consists of a stout pillar of wood about 2½ yards high, at the top of which is a brass pulley, the axle of which rests and turns upon four other wheels, called *friction wheels*, because they serve to diminish friction.

Two equal weights M and M' are attached to the extremities of a fine silk thread, which passes round the pulley. A time-piece, H, fixed to the pillar is regulated by a seconds pendulum, P, so arranged that, by means of the lever D, it removes the support of the small plate *i*, and lets the weight M fall. But this weight being counter-balanced by the equal weight M', is caused to move slowly by the small overweight *m*, and its motion is indicated by the scale Q, divided into feet and inches. The plates A, A', C, C', and the rings B, B' may be fixed by screws at any part of the scale. The plates arrest the descending weight M, but the rings only arrest the bar or overweight *m*, which causes the motion; so that, after passing through them, the weight M, in consequence of its inertia, will move on uniformly with the velocity it has acquired on reaching the ring. If M or M' weighs 7½ ounces, for example, and the bar *m* weighs only 1 ounce, then, while if left to fall freely, *m* would pass through 16 feet in the first second, it will, when placed on M, only pass through 1 foot, because it has sixteen times as much matter to move ($7\frac{1}{2} + 7\frac{1}{2} + 1 = 16$). The ratios of times, spaces, and velocities, however, will be exactly the same.

To operate the instrument, place the hand of the dial behind the zero point, and adjust the lever D to support the plate *i*, with the weights M and *m* resting on it. Then put the pendulum in motion, and as soon as the hand reaches zero, the plate will fall, and the weights will descend. The stop-plate A, after a few trials, can be so placed that the weights will reach it exactly on the expiration of a second; then remove it, and put the ring B in its place, which will stop only the overweight *m*. In a similar manner place the plate C for two seconds; then it will be obvious that the weight *m* being stopped at B, the weight M will pass over B C, exclusively by its own inertia, and thus B C will indicate the velocity of the falling body at the expiration of one second. Other experiments similarly exhibit the velocities and spaces for two or more seconds.

80. **Ascending Bodies.**—When a body is thrown perpendicularly upward with any velocity, it will rise against the force of gravity to that height from which it will fall to the earth with a velocity equal to that with which it started.

Suppose a body were projected upward with a velocity of 160.8 feet a second; as it acquires a velocity of 32.16 feet in one second, it would require five seconds to acquire 160.8 feet in falling freely from a point above the surface of the earth. Hence it will continue to ascend during five seconds, and will rise to the height of 402 (16.08×25) feet. In this statement no allowance is made for the resistance of the air.

81. **Projectiles.**—Any body, such as a stone or a cannon-ball, thrown at any angle to the horizon is a projectile. The horizontal distance between the point from which it is thrown and the point at which it falls is called its *range*, or *random*; the line which it may be conceived to describe, its *path*.

Independently of the resistance of the air, the greatest range is attained when

a body is thrown at an angle of 45°; but, practically, owing to that resistance, the angle is 40°. The path of a projectile is that kind of curve known as a *parabola*.

The projectile force does not affect the action of gravity on the body; for, if it be projected horizontally, it will reach the ground in the same time which it would have required if dropped perpendicularly from the same height.

II.—WEIGHT.

82. **Weight** is the measure of the effect of gravity acting upon a body. (Art. 29.)

As the attraction of the earth is exerted upon every one of the constituent molecules of a body, it must vary with the mass, or quantity of matter. That is to say, if one body has twice the mass of another, its weight will be twice as great. Thus the weight of a body becomes a measure of the quantity of matter which it contains. It is true the attraction between the earth and the body is mutual, but the effect of the body's attraction upon the earth is inconsiderable.

83. The weight of a body varies with its distance from the center of the earth, both above and below the surface, but in different proportions. Above the surface it varies inversely as the square of its distance from the center; but below the surface, it varies directly as the distance.

Thus, taking the distance of the center of the earth from its surface as 4,000 miles (which it is nearly), a body that weighs a pound at the surface, would weigh, at an elevation of 1,000 miles from the surface, about 10¼ ounces. For the distances from the center, in that case, are 4,000 miles and 5,000 miles, or as 4 : 5, and the squares, 16 : 25. Hence the inverse ratio would be $\frac{16}{25}$, and $\frac{16}{25}$ of 16 ounces is equal to 10¼ ounces.

But if the body could be sunk 1,000 miles below the surface, its weight would be three-fourths of a pound, or 12 ounces, because the ratio would be as 4,000 to 3,000, or as 4 to 3.

The second case looks like an exception to the law of universal gravitation, but it is not. The difference arises from the fact that, when a body is below the surface of the earth, it is acted upon by the attraction of a smaller sphere, since it is only the *sphere below* that affects it. Thus if it were 1,000 miles below the surface of the earth, the radius of the attracting sphere would be 3,000 miles, the hollow shell above having no attracting effect, or rather the attractions of its different parts neutralizing one another. But spheres are to each other as the *cubes* of their radii, and as the weight varies *inversely* as the squares of the distances, or radii, the resulting ratio is directly as the distances themselves ($3^2 \times 4^3 : 4^2 \times 3^3 = 4 : 3$).

84. Gravity or weight is affected by the form of the earth and its axial rotation.

The earth not being a perfect sphere, but flattened at the poles, the weight of a body will be greatest at the poles, and least at the equator. Gravity is $\frac{1}{178}$ greater at the former than at the latter.

By the action of the centrifugal force (Art. 55), which causes a slight tendency of bodies to fly off from the surface of the earth with which they are revolving, gravity is also diminished. At the equator the loss of weight due to this cause is equal to $\frac{1}{289}$. The combined effect of both these causes is to make the effect of gravity at the equator less by about $\frac{1}{192}$ of its value at the poles.

III.—MOLECULAR FORCES.

85. **Molecular attraction** is the force which tends to bring the molecules of a body together. It is called, according to the circumstances under which it acts, *cohesion*, *affinity*, or *adhesion*.

Molecular attraction is exerted only at indefinitely small distances, its effect being inappreciable when the distance between the molecules is appreciable.

The various phenomena which bodies present show that their molecules are under the influence of two contrary forces, one tending to bring them together, the other to separate them. The latter is due to the moving force which the molecules themselves possess. It is the mutual relation between these forces—the preponderance of the one or the other—which determines the molecular state of a body, whether it be solid, liquid, or gaseous. (Art. 4.)

86. **Cohesion** is the force which unites adjacent molecules of the same nature; for example, molecules of water or of iron.

Cohesion is strongly exerted in solids, less strongly in liquids, and scarcely at all in gases. It varies with the temperature and the arrangement of the molecules. Heat, by increasing the moving force of the molecules, diminishes the cohesion. The tempering of steel changes the molecular arrangement, and increases cohesion.

In large masses of liquids gravity overcomes cohesion; in small masses cohesion prevails. Hence the spherical form of drops of rain or dew.

The force which is exerted between molecules not of the same kind is called *chemical affinity*. Thus while cohesion binds together the molecules of water, it is chemical affinity which unites the two elements, oxygen and hydrogen, of which the water is composed.

87. **Adhesion** is the molecular attraction exerted between the *surfaces* of bodies in contact.

1. Adhesion takes place between solids. If two leaden bullets are cut with a penknife so as to present two equal polished surfaces, the two faces when pressed together will firmly adhere to each other. The same experiment may be made with two equal pieces of glass polished and made plane. This is due to adhesion, which does not essentially differ from cohesion.

2. Adhesion also takes place between solids and liquids, and is stronger than

between solids. Thus if, in the above experiment, a thin layer of oil is interposed between the plates, they adhere firmly; but, when pulled asunder, each plate is found to be moistened by the oil, showing the stronger adhesion of the latter.

3. Adhesion operates also between solids and gases. If a glass or metal plate be immersed in water, bubbles of air will rise to the surface, which must be due to the layer of air which covered the plate previous to immersion.

Writing and drawing with pencil or chalk depend on the adhesion of solids. These are readily erased, because the adhesion is only on the surface; while, in writing with ink, the liquid penetrates into the pores of the substance, and carries the solid coloring matter with it, which is left in cohesion with the particles, when the ink evaporates.

IV.—PROPERTIES PECULIAR TO SOLIDS.

88. The **specific properties** of solids are *elasticity, tenacity, ductility, malleability,* and *hardness.*

89. While elasticity is one of the general properties of matter, it exists *in solids* in certain special forms—the elasticity of *traction,* the elasticity of *torsion,* and the elasticity of *flexure.*

The elasticity of traction is exhibited when rods or wires are made to support weights; that of torsion, when a weight is suspended by a wire, and the latter after being twisted untwists itself. The elasticity of flexure is seen in watch and carriage springs, spring-balances, etc. Bodies of different materials vary greatly with respect to these properties.

The *torsion balance* is a delicate instrument designed to measure minute forces. It consists of a metal wire from which is suspended a metal sphere having an index or pointer connected with it, which moves round on a circular graduated plate beneath. The force required to turn the index from its position of equilibrium through a certain angle, called the *angle of torsion,* is called the *force of torsion.* (See Art. 319.)

90. **Tenacity** is the resistance which a body opposes to the total separation of its parts.

Ordinary tenacity is determined in different bodies by forming them into wires, and ascertaining the weight required to break them.

Tenacity is directly proportioned to the breaking weight, and inversely as the area of a transverse section of the wire. Thus, if of two wires one breaks with a weight of 25 pounds, and the other with 50 pounds, while the area of a transverse section of the first is one-fourth that of the second, the tenacity of the first is twice as great as that of the second, being as $25 \times 4 : 50 \times 1$ or as 2:1.

Of all metals cast-steel has the greatest tenacity. But fibers of unspun silk and cotton possess this property in a still higher degree. Cotton fibers will support millions of times their own weight.

Tenacity also varies with the form of the body. A cylindrical body has greater tenacity than a square one of the same size, and a hollow cylinder more than a solid one; and this is true both as to its resistance to a crushing weight and to that of a drawing force. Hence, the bones of animals, the feathers of birds, and the stems of plants are of the latter form. Tenacity diminishes rapidly with an increase of temperature.

91. **Ductility** is the property in virtue of which bodies can be drawn out in the form of wire.

Bodies have very different degrees of this property. The most ductile metal is platinum. Wollaston obtained a wire of it only .00003″ of an inch in diameter. A mile of such wire would have weighed but little more than a grain.

92. **Malleability** may be considered as a modification of ductility, exhibited by bodies on being hammered into thin plates.

Both malleability and ductility depend upon the property in virtue of which certain bodies change their forms through the effect of pressure or traction. The most malleable metal is gold, which has been beaten into leaves about the one three-hundred-thousandth of an inch thick.

93. **Hardness** is the resistance which bodies offer to being scratched by others.

The diamond is the hardest of all bodies, for it scratches all, and is not scratched by any. Metallic alloys are harder than the pure metal. Hence in coinage and the manufacture of jewelry, gold and silver are alloyed with copper to give additional hardness.

By sudden cooling after being raised to a high temperature, many bodies become very hard. This is called *tempering*. All cutting instruments are made of tempered steel.

The resistance of a body to compression does not depend upon its hardness. Wood offers far greater resistance to the blow of a hammer than the diamond or glass, although the latter is very much harder. This is due to the property called *toughness* in the one, and to that named *brittleness* in the other.

A body can be made to cut others much harder than itself, by causing it to move with great velocity. A disc of wrought-iron rotating rapidly will cut into the hardest substances, such as agate and quartz.

Annealing is a process by which metals and some other substances are rendered soft and flexible by being heated and allowed to cool slowly. The brittleness of glass, for example, can be greatly modified by this process.

SYNOPSIS FOR REVIEW.

I.—UNIVERSAL GRAVITATION:

1. *Definition.*
2. *General Law.*
3. *Gravity:*
 1. Center of.
 2. Line of direction.
4. *Equilibrium:*
 1. Stable.
 2. Unstable.
 3. Neutral.
5. *The Balance:*
 1. Principle.
 2. Construction.
 3. Different kinds.
6. *Falling Bodies.*
 1. Law of.
 2. Illustration of the law.—Atwood's machine.
 3. Rules for problems.
7. *Ascending Bodies*—Law of height and velocity.
8. *Projectiles.*
 1. Definition.
 2. Range, or random.
 3. Path.

II.—WEIGHT:

1. *Definition.*
2. *Law of Variation:*
 1. Due to distance above the earth's surface.
 2. Due to distance below the earth's surface.
 3. Due to shape of the earth.
 4. Due to motion of the earth.

III.—MOLECULAR FORCES:

Molecular Attraction.

1. Cohesion, in
 1. Solids.
 2. Liquids.
 3. Gases.
2. Adhesion, between
 1. Solids.
 2. Solids and liquids.
 3. Solids and gases.

IV.—PROPERTIES PECULIAR TO SOLIDS:

Special Properties:

1. Elasticity:
 1. Of traction.
 2. Of torsion.
 3. Of flexure.
2. Tenacity:
 1. Definition of.
 2. Law of.
 3. Examples.
3. Ductility.
4. Malleability.
5. Hardness.
 Tempering.
 Annealing.

 1. Definition.
 2. Examples.

APPLICATION OF PRINCIPLES.

Explain the following phenomena: 1. Why bodies tend to the center of the earth. 2. Why the moon revolves around the earth. 3. How the weight of a body determines the quantity of matter it contains. 4. Why the mason uses a plumb-line in building a wall. 5. The tempering of steel. 6. The untwisting of a twisted wire. 7. The use of a door-spring. 8. Why a wagon overloaded at the top is easily upset. 9. Why it is difficult to walk on stilts. 10. Why a person carrying a load on his back leans forward. 11. The rising of bubbles on the surface of water when a plate of metal is immersed in it. 12. The spherical form of a drop of rain. 13. The increase in velocity of a falling body. 14. The decrease in velocity of a body rising perpendicularly from the surface of the earth. 15. The adhering of two surfaces of polished or ground glass. 16. The simultaneous fall of a piece of lead and a feather in vacuum. 17. What holds the particles of a solid together. 18. The loss of weight which a body undergoes when taken from the poles to the equator. 19. The rolling of a spherical body down an inclined plane. 20. Why the path of a projectile is a curve.

PROBLEMS FOR EXERCISE.

1. Were a body that weighs 100 pounds at the surface of the earth to be carried 1,500 miles above its surface, what would it weigh, taking the diameter of the earth at 8,000 miles?

2. If the same body were sunk 500 miles below the surface of the earth, what would it weigh? What would it weigh at the center of the earth?

3. At what height above the earth's surface would it lose half its weight? At what depth below the surface?

4. If the moon were four times as far from the earth as it is, how much less would the mutual attractions of the two bodies be?

5. Taking the diameter of Jupiter at 88,000 miles, and the earth's at 8,000, what would a body which weighs 100 pounds at the earth's surface weigh at the surface of Jupiter, the density of the latter body being one-fourth that of the earth?

6. How long will a body be in falling from a height of 500 feet?

7. If a body has been falling 3½ seconds, from what height did it fall?

8. What velocity did it have when it reached the surface?

9. With what velocity must a body be thrown perpendicularly upward from the surface of the earth to reach a height of 1,300 feet?

10. How long will a ball projected perpendicularly upward with a velocity of 1,608 feet a second continue to rise? What will be its velocity at the end of the third second?

11. Two bodies reach the surface of the earth at the same time, one having been falling 2½ seconds longer than the other. Now, if the first fell from a height of 804 feet, how long was the other in falling?

12. If from the top of a tower 201 feet high a body is projected horizontally with a velocity of 50 feet a second, how far from the base of the tower will it strike the ground, and how long will it be in falling?

13. Which has the greater momentum, a car weighing 30 tons moving at the rate of 20 miles an hour, or a ball weighing 500 pounds which descends to the earth from the height of 2,500 feet?

14. A stone is thrown from a balloon with a velocity of 400 feet in a second. In how many seconds will the velocity be increased 800 feet a second, and through what distance will the stone have fallen?

15. If a projectile is thrown vertically upward to a height of 1,500 feet, disregarding the resistance of the air, in how many seconds will it return, and with what velocity will it reach the earth?

CHAPTER III.

LIQUIDS.

I.—HYDROSTATICS.

94. Hydrostatics treats of the conditions of the equilibrium of liquids, and of the pressure they exert.

That branch of physics which treats of the motion of liquids is called *hydrodynamics;* that which applies the principles of the science to the raising or conducting of water in pipes is known as *hydraulics.*

While the molecules of liquids are displaced by the slightest force, their fluidity is not perfect, since their particles slightly adhere to each other. Gases possess fluidity in a higher degree. They are not, however, perfectly fluid, as their particles slightly adhere; and when a mass of fluid is set in motion, there is a tendency on the part of the stationary particles to drag back those adjacent to them. This slight adherence of the particles is called *viscosity.*



Fig. 28.

The distinction between these two forms of matter is, that liquids are almost incompressible and inexpansible, while gases are peculiarly compressible and expand spontaneously.

The slight compressibility of liquids has been shown by the following experiment, made with the apparatus shown in Fig. 28, called the *piezom'eter* (Greek, *piezo*, compress, and *metron*, measure). It consists of a strong glass cylinder with very thick sides, having an internal diameter of about 3¼ inches. The base of the cylinder is firmly cemented into a wooden foot, and on its upper part is fitted a metallic cylinder closed by a cap, which can be unscrewed. In this cap there is a funnel, R, for pouring water into the cylinder, and a small barrel hermetically closed by a piston, which is moved by a screw, P. In the inside of the apparatus is a glass vessel, A, containing the liquid to be compressed. The upper

part terminates in a very small tube which dips under mercury, O. This tube has been previously divided into parts of equal capacity, and it has been determined how many of these parts the vessel A contains. The glass tube B containing air is closed at one end, the other dipping under the mercury. When there is no pressure on the water in the cylinder, this tube is full of air; but when the water in the cylinder is compressed by the screw P, the pressure is transmitted to the mercury, which rises in the tube, compressing the air which it contains. The graduated scale shows the reduction of volume, which indicates the pressure on the liquid in the cylinder. Thus the pressure on the water in the cylinder is communicated to the mercury, which, rising in the tube, imparts it to the liquid in the vessel A, and the scale shows the amount of compression.

Under a pressure equal to that of the atmosphere (15 pounds to the square inch), mercury is compressed to the extent of one two-hundred-thousandth of its volume; water, one twenty-thousandth. The compressibility of sea-water is about one twenty-three-thousandth; it is not materially denser even at great depths, the increase at the depth of a mile being only one one-hundred-and-thirtieth.

Whatever be the pressure to which a liquid is subjected, experiment shows that, as soon as the pressure is removed, the liquid regains its original volume. Hence it is concluded that *liquids are perfectly elastic.*

95. **Equality of Pressure.**—Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and

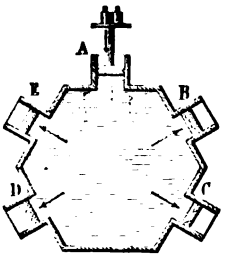


Fig. 29.

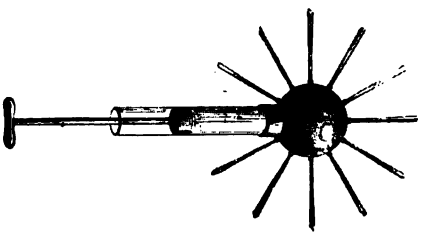


Fig. 30.

acts with the same force on all equal surfaces, and in a direction at right angles to those surfaces.

This is often called Pascal's law, having been first enunciated by him. It assumes that the liquids are perfectly fluid, and uninfluenced by the action of gravity.

To illustrate this, let us conceive a vessel of any given form (Fig. 29) in the sides of which are placed various cylindrical apertures, all of the same size, and closed by movable pistons. Now, if this vessel be filled with liquid, and unaffected by the action of gravity, the pistons will have no tendency to move. Then if a weight of 5 pounds be placed upon the piston A, it will be pressed inward,

and the pressure will be communicated to each of the other pistons, B, C, D, and E, which will be forced outward by a pressure equal to 5 pounds, their surfaces being equal; but if the surface of one were ten times as great as that of A, the pressure upon it would be ten times as much, or 50 pounds.

That the pressure is transmitted in all directions can be shown by the following experiment: A cylinder provided with a piston is fitted into a hollow sphere (Fig. 30) in which small cylindrical jets are placed perpendicular to the sides. The sphere and the cylinder being both filled with water, when the piston is forced in, the liquid spouts from all the orifices, not merely from that opposite to the piston.

96. In consequence of the equal distribution of pressure exerted upon any portion of the surface of a liquid contained in a vessel, any weight, however small, may be made to balance any other weight, however large.

This is illustrated in Fig. 31. Two cylinders of different diameters are joined by a tube and filled with water. On the surface of the liquid are two pistons P and p, which hermetically close the cylinders and move without friction. Let the area of the large piston be, for example, thirty times that of the small one. Then if a weight, say of one pound, be placed upon the small piston, the pressure will be transmitted to the water and to the large piston; and as this pressure is that of a pound on every portion of its surface equal to that of the small piston, the large piston must be exposed to an upward pressure of thirty pounds; and if that weight be placed upon it, both pistons will be in equilibrium. It is obvious that if the piston P were one thousand times as large as the small one p, one pound could be made to balance a thousand pounds, and so on.

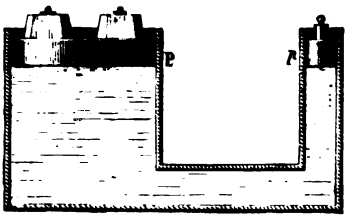


Fig. 31.

97. **Pressure Independent of the Shape of the Vessel.**—The pressure exerted by a liquid, in virtue of its weight, on any portion of the liquid, or on the sides of the containing vessel, depends on the depth and density of the liquid, without regard to the quantity of the liquid or the shape of the vessel.

Hence a very small quantity of water can be made to produce a very great pressure. Let us imagine any vessel—a cask, for example—filled with water, and having a long, narrow tube fitted into the side. If water is poured into the tube, there will be a pressure on the bottom of the cask equal to the weight of a column of water whose base is the bottom itself, and whose height is equal to that of the water in the tube. The pressure may be made as great as we please. By means of a narrow thread of water forty feet high, Pascal succeeded in bursting a very strongly constructed cask. On this principle, is constructed the toy known as the *hydrostatic bellows;* also the hydraulic press. (Art. 103.)

The pressure of fresh water at the depth of 1 foot is 62½ pounds, or 1,000 ounces upon every square foot, because a cubic foot of water weighs that amount. In sea water the pressure is 64.37 pounds. It is obvious that at great depths the pressure is enormous.

The number of square feet in the area of the bottom of a vessel multiplied by the perpendicular height in feet, and that product by the weight of a cubic foot of the liquid, will give the pressure on the bottom. It is obvious that this rule takes no account of the shape or contents of the vessel.

98. **Pressure on the Side of a Vessel.**—The total pressure on any part of the side of a vessel is equal to a column of liquid which has this portion of the side for its base, and whose height is the vertical distance from the center of gravity of the portion to the surface of the liquid.

This follows from the fact that the pressure caused by gravity in the mass of a liquid is transmitted in every direction; and, therefore, at every point of the side of any vessel a pressure is exerted at right angles to the side, if it be a plane surface. The resultant of all these pressures is the total pressure on the sides. If the side be a curved surface, the same rule gives the pressure on the surface, but the total pressure is no longer the resultant of the fluid pressures.

The pressure on the side of a vessel is the mean of all the pressures from the surface, where it is nothing, to the bottom, where it is measured by the area of the bottom multiplied by the height of the liquid. Hence, in a cubical vessel, the pressure on any side is equal to one-half the pressure on the bottom. Therefore, to find the pressure on the side of a vessel, multiply the number of square feet in the area of the side by half the perpendicular height in feet, and that product by the weight of a cubical foot of the liquid.

99. **Hydrostatic Paradox.**—While the pressure of a liquid on the bottom of a vessel depends not on the form of the vessel nor on the quantity of liquid contained, but simply on the height of the liquid above the bottom, the pressure of the vessel itself with its contents on the body which supports it depends upon their actual weight.

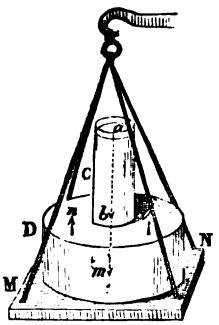


Fig. 32.

Thus while the addition of an ounce of water might be so applied as to cause a pressure sufficiently great to burst the strongest vessel containing the fluid, it would be simply the additional weight of an ounce on that which supports the vessel. This, at first view, seems absurd, though it is true, and hence is called the *hydrostatic paradox*.

It is illustrated in Fig. 32. C D is a vessel composed of two cylindrical parts of unequal diameters, and filled with water to *a*. The bottom of the vessel supports the same pressure as if its diameter were equally large throughout. Now, if the

area of the bottom of the large cylinder is twenty-five times as great as that of the small one, and an ounce of water is poured in at a, the additional pressure on the bottom of C D will be equal to that of 25 ounces; but the whole vessel C D and its contents will weigh just one ounce more. For the upward pressure upon the surface $n\,o$ of the vessel balances the downward pressure on m, so that the pressure exerted on the bottom of the vessel is not all transmitted to the scale M N.

Equilibrium of Liquids.

100. **In a single vessel** a liquid remains at rest, (1) when its surface is everywhere perpendicular to the resultant of the forces which act on its molecules; and (2) when every molecule of the mass of the liquid is subject, in every direction, to equal and contrary pressures.

To illustrate the first condition, let us suppose that $m\,p$ (Fig. 33) is the resultant of all the forces acting on any molecule m on the surface, and that this surface is inclined in reference to the force $m\,p$. The latter can, consequently, be decomposed into two forces, $m\,q$ and $m\,f$, the one perpendicular to the surface of the liquid, and the other to the direction $m\,p$. Now the first force $m\,q$ would be destroyed by the resistance of the liquid, while the second would move the molecule in the direction $m\,f$, which shows that the equilibrium is impossible.

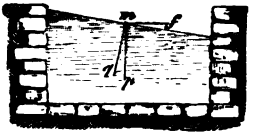


Fig. 33.

If gravity be the force acting on the liquid, the direction $m\,p$ is vertical; hence if the liquid is contained in a basin or vessel, the surface is plane and horizontal. In the case of the ocean, the surface is curved, owing to its great extent, because while it is perpendicular to the direction of gravity, that direction changes at every point. This is true of the surface of all liquids, but in a vessel of small extent the variation from a plane surface is infinitesimal.

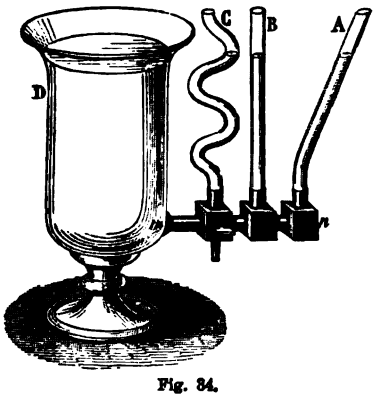


Fig. 34.

101. **In several communicating vessels,** of any variety of form, there will be equilibrium when the liquid in each vessel satisfies the two preceding conditions, and further, when the surfaces of the liquids in all the vessels are in the same plane.

In the vessels A, B, C, and D (Fig. 34), which communicate with each other, let us consider any transverse section of the tube $m\,n$. The liquid can remain in equilibrium only as long as the pressures which this section supports from m in

the direction of n, and from n in the direction of m, are equal and opposite. Now these pressures are respectively equal to the weight of a column of water whose base is the supposed section, and whose height is the distance from the center of gravity of this section to the surface of the liquid. If we conceive, then, a horizontal plane $m\ n$ drawn through the center of gravity of this section, it will be seen that there will be equilibrium only as long as the height of the liquid above this plane is the same in each vessel.

102. When liquids of different densities are contained in the same vessel, there will be stable equilibrium only when the liquids

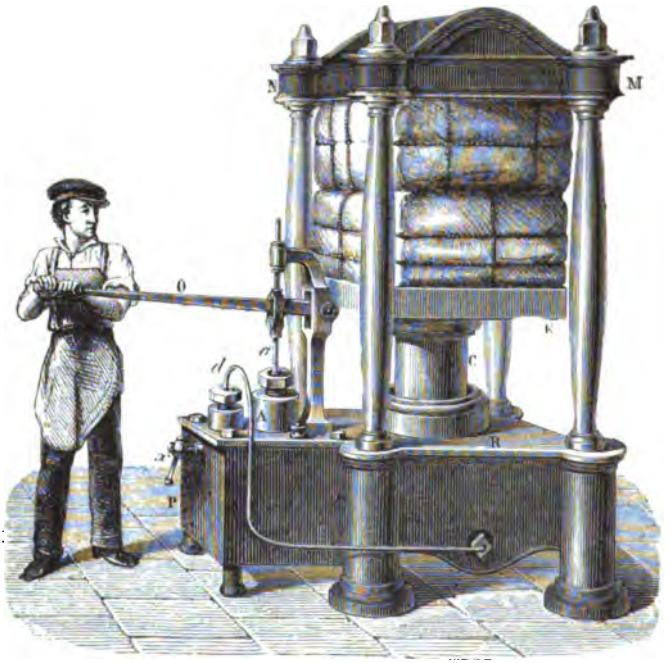


Fig. 35.

are arranged in the order of their decreasing densities from the bottom upward.

This can be shown by the *phial of four elements*, which consists of a long, narrow bottle containing mercury, water saturated with carbonate of potass, alcohol colored red, and petroleum. When the phial is shaken the liquids mix; but when it is allowed to rest they separate, the mercury sinking to the bottom, on which rest in their order the water, the alcohol, and the petroleum.

103. **Hydraulic Press.**—In the hydraulic press, a machine by

means of which an enormous pressure may be produced, the law of the equality of pressure of liquids has received an important application. Its principle is due to Pascal, but it was first constructed by Bramah in 1796.

It consists of a cylinder (Fig. 35) with very strong, thick sides, in which there is a cast-iron ram C, working water-tight in the collar of the cylinder. On the ram there is a cast-iron plate, K, on which the substance to be pressed is placed. Four strong columns serve to support and fix a second plate M N. By means of a leaden pipe *d* the cylinder, which is filled with water, communicates with a small force-pump A, which works by means of a lever O. When the piston *a* of this pump ascends, a vacuum is produced, and the water rises in the tube. When the piston *a* descends, it drives the water into the cylinder by the tube *d*. The pressure depends on the relation of the pistons C and *a*. If the former has a transverse section fifty or a hundred times as large as the latter, the upward pressure on the large piston will proportionally exceed that exerted on the small one. By means of the lever O an additional advantage is gained. If the distance from the fulcrum to the point where the power is applied be five



Fig. 36.

times the distance from the fulcrum to the piston *a*, the pressure on *a* will be five times the power. Thus if a man acts on O with a force of 60 pounds, the force transmitted by the piston *a* will be 300 pounds, and the force which tends to raise the piston C will be 30,000 pounds, supposing that the section of C is a hundred times that of *a*.

The hydraulic press is used in pressing cloth and paper, in extracting the juice of beet-root, in compressing hay and cotton, in expressing oil from seeds, and in bending iron plates. It also serves to test the strength of cannon, of steam boilers, and of chain cables, and aids in launching ships.

104. The **water-level** is an application of the conditions of equilibrium in communicating vessels.

It consists of a metal tube bent at both ends, in which are fitted glass tubes D and E (Fig. 36). It is placed on a tripod, and water is poured into it until it

rises in both legs. When the liquid is at rest the level of the water in both tubes is the same—that is, in the same horizontal plane. This instrument is used in leveling, or ascertaining how much one point is higher than another, as, for example, B than A. The height of the latter being indicated on the leveling-staff A M, and subtracted from the height of the level, the difference in height between A and B becomes known.

The surface of standing water is not perfectly level, owing to the general curvature of the earth's surface, of which it partakes. This amounts to about eight inches per mile.

The *spirit-level* is constructed on a similar principle. It consists of a glass tube A B (Fig. 37) very slightly curved. It is filled with alcohol, with the ex-



Fig. 37.

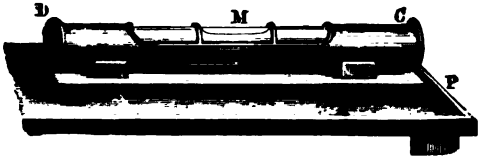


Fig. 38.

ception of a bubble of air, which tends to occupy the highest part. The tube is placed in a brass case C D (Fig. 38), which is so arranged that when it is in a perfectly horizontal position the bubble of air is exactly midway between the two points marked in the case.

105. **Artesian wells** illustrate the tendency of water to find its level. They are deep borings through different strata of the earth's surface, until water is reached, which, to find its level, rushes up to or near the surface.

These wells derive their name from Artois, in France, where it has long been customary to dig them. It seems, however, that, at a very remote period, wells of this kind were dug in China and Egypt.

Of the strata composing the earth's crust some are permeable to water, such as sand, gravel, etc., and some not, as clay. Fig. 39 represents a geographical basin in which two impermeable strata A B and C D inclose a permeable layer K K. The rain-water falling on the part of this layer which comes to the surface, called the *outcrop*, will filter through it and collect in the hollow of the basin, whence it is unable to escape. If now a well, I, be vertically bored to this basin, the water will rise through it to, or nearly to, the level of the outcrop.

The waters which supply artesian wells often come from a distance of sixty or seventy miles. The depth varies in different places. The well at Grenelle, Paris, is 1,800 feet deep, and gives 656 gallons of water a minute. There are

two wells in Chicago, about 700 feet deep, that afford a daily supply of about 430,000 gallons of water.

106. **Principle of Archimedes.**—Every body immersed in a liquid is acted on by two forces—gravity, which tends to lower it,

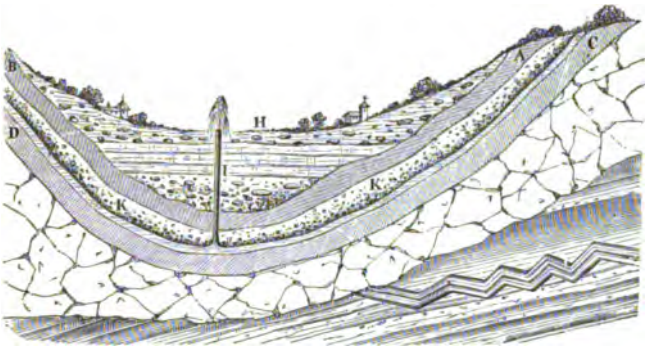


Fig. 39.

and the buoyancy of the liquid, which tends to raise it with a force equal to the weight of the liquid displaced. The weight of the body is either totally or partially overcome by this buoyancy, from which it is concluded that *a body immersed in a liquid loses a part of its weight equal to the weight of the displaced liquid.*

The forces acting on an immersed body are illustrated in Fig. 40, which represents a cube immersed in water. The pressures upon the four vertical faces being clearly in equilibrium, we need consider only the pressures on the horizontal faces A and B. The first is pressed downward by a column of water, the base of which is the face A, and its height A D, while the lower face B is pressed upward by a column of water, the base of which is the face itself, and its height B D. The cube, therefore, is urged upward by a force equal to the difference between these two pressures, which is manifestly equal to the weight of a column of water having the same base and height as the cube. Consequently, this upward pressure is equal to the weight of the volume of water displaced by the immersed body.

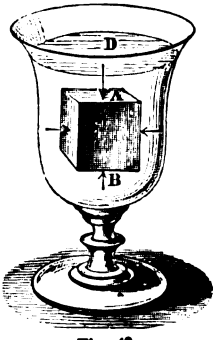


Fig. 40.

This principle, which is the basis of the theory of immersed and floating bodies, is called the principle of Archimedes, who is said to have discovered it while endeavoring to ascertain how much alloy the goldsmith whom Hiero, King of Syracuse, had employed to make him a crown of pure gold, had mixed with the metal. The principle was

suggested to Archimedes while he was in the bath, and it is said he rushed into the street, exclaiming *Eureka!*—I have found it.

The principle of Archimedes affords a method of ascertaining the volume of a body of any shape, provided it is not soluble in water. The body is weighed first in air, and then in water, and the loss of weight is the weight of the displaced water, which is the same in volume as that of the body; and from its weight the volume can easily be calculated.

107. **Floating Bodies.**—A body when floating is acted on by two forces—its weight, which acts vertically downward through its center of gravity, and the resultant of the fluid pressures, which acts vertically upward, through the center of gravity of the fluid displaced.



Fig. 41.

When the body is at rest these two forces must be equal and must act in opposite directions. Hence the following are the conditions of equilibrium:

1. *The floating body must displace a volume of liquid the weight of which is equal to that of the body.*

2. *The center of gravity of the floating body must be in the same vertical line as that of the fluid displaced.*

Cartesian Diver.—The different effects of suspension, immersion, and floating are represented in the well-known hydrostatic toy called the *Cartesian diver* (Fig. 41). It consists of a glass cylinder nearly full of water, to the top of which a brass cap, provided with a piston, is hermetically fitted. In the liquid there is a little porcelain figure attached to a hollow glass ball *a*, which contains air and water, and floats on the surface. In the lower part of this ball there is a little hole by which water can enter or escape, according as the air in the interior is more or less compressed. The quantity of water in the globe is such that very little more is required to make it sink. If the piston be slightly lowered, the air is compressed, and this pressure is transmitted to the water of the vessel and the air in the bulb. The consequence is, that a small quantity of water penetrates into the bulb, which thus becomes heavier and sinks. If the pressure is withdrawn, the air in the bulb expands, and expels the excess of water which had entered it; and now being lighter, the figure rises. Instead of the brass cap and piston, a sheet of india-rubber may be used, which may be pressed with the hand, producing the same effects.

The swimming-bladder of the fish acts on the same principle, the fish by a muscular effort compressing or dilating it at pleasure. As the human body is, on the whole, lighter than an equal volume of water, it floats on the surface. Swimming depends upon giving the body such a position that the head may be above the water.

II.—SPECIFIC GRAVITY.

108. Specific gravity is the weight of a body compared with a quantity of water of the same volume.

The standard is distilled water at a temperature of 39.2° F. In order to calculate the specific gravity of a body, all that is required is to determine its weight and that of an equal volume of water, and divide the first by the second. The quotient will be the specific gravity. Hence the following rule:

109. To find the specific gravity of a solid, weigh it first in

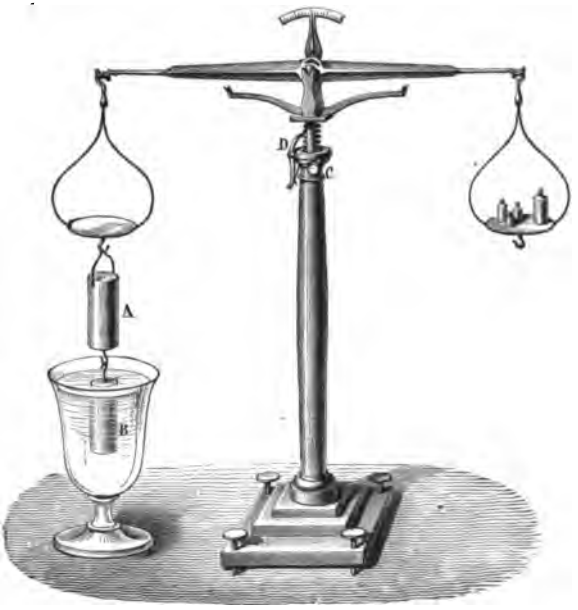


Fig. 42.

air and then in water, and the quotient found by dividing its weight in air by its loss of weight in water will be the specific gravity.

The truth of this principle is shown by means of the *hydrostatic balance* (Fig. 42), which is an ordinary balance having each of its pans furnished with a hook. The beam can be raised by means of a toothed rack worked by a little pinion C, a catch D holding the rack when it has been raised. The beam being raised, a hollow brass cylinder A is suspended to one of the pans; and below this is a solid cylinder whose volume is equal to the capacity of the other cylinder. After the weight has been exactly counterpoised, the cylinder A is filled with water. This disturbs the equilibrium; but, if the solid cylinder B is allowed to descend in a

vessel of water, the equilibrium is restored, showing that the loss of weight in the cylinder B is equal to the water poured into A.

To find the specific gravity of a solid by the hydrostatic balance, it is first weighed in air, and is then suspended to the hook of the scale-pan and weighed in water. In this way the loss of weight is ascertained.

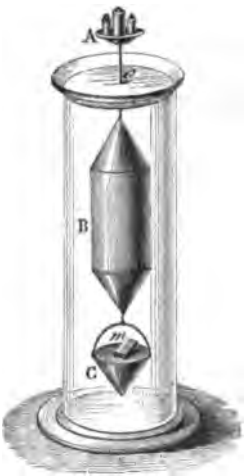


Fig. 43.

If the body is lighter than water, a heavier substance of known weight can be attached to it, and both weighed together. The loss of weight of the two less the loss of weight of the heavy body will be the loss of weight of the lighter body, and this divided by its weight in air will give the specific gravity.

Nicholson's Hydrometer.—This apparatus is represented in Fig. 43. It consists of a hollow metal cylinder B, to which is fixed a cone C, loaded with lead. At the top is a stem to which is attached a pan for holding the substance to be weighed, and on which is marked a standard point *o*. It is first required to know the weight which must be placed in the pan to sink the hydrometer to *o*. Let us suppose this to be 125 grains. Suppose we desire to ascertain the specific gravity of sulphur, we select a piece weighing less than 125 grains, place it on the pan, and add sufficient weight to sink the stem to *o*. This added weight deducted from 125 grains will obviously give the weight of the sulphur. Now place the piece of sulphur in the lower pan at C, immersed in water, and the loss of weight will cause the hydrometer to rise. Weight is then added to the pan to cause it to sink to *o*, and that weight represents the loss of weight of the sulphur when weighed in water. If the body in question is lighter than water, it is confined to the lower pan by a small movable cage of fine wire.

If the body whose specific gravity is to be determined is soluble in water, it is weighed in some liquid in which it will not dissolve, such as oil of turpentine, the specific gravity of which is known. Then the specific gravity of the body is found by multiplying that obtained in the experiment by the specific gravity of the liquid used.

The foll wing table gives the specific gravity of certain well-known substances (at 32° F., compared with water at 39.2° F.):

Platinum (rolled)	22.069	Diamonds	3.531 to 3.501
" (cast)	20.337	Flint glass	3.329
Gold (cast)	19.258	Statuary marble	2.837
Lead (cast)	11.352	Native sulphur	2.033
Silver (cast)	10.474	Ivory	1.917
Copper (cast)	8.788	Anthracite coal	1.800
Brass	8.383	Melting ice	.930
Iron (cast)	7.207	Beech wood	.852
Tin (cast)	7.291	Oak wood	.845
Zinc (cast)	6.861	Cork	.240

110. The specific gravity of a liquid may be determined by the loss of weight it occasions in a solid, and by comparing it with the loss of weight which the same solid undergoes when weighed in water.

This will be obvious from the fact that the loss of weight in each case represents the weight of an equal volume of the liquid used; and the one required being divided by that of water gives the specific gravity. The following shows the specific gravity of a few well-known liquids (at 32° F., compared with water at 39.2° F.):

Mercury	13.598	Sea water	1.026
Sulphuric acid	1.841	Olive oil	.915
Chloroform	1.525	Oil of turpentine	.870
Glycerine	1.260	Petroleum	.836
Blood	1.060	Alcohol (absolute)	.793
Milk	1.032	Ether	.718

III.—CAPILLARY ATTRACTION.

111. Capillary attraction is the name given to the tendency of liquids to rise in fine tubes.

The term *capillary* is derived from the Latin word *capillus*, a hair, and is applied to this class of phenomena because they are best seen in tubes as fine as hair. These phenomena may all be referred to the attraction of the liquid molecules for each other, and to the attraction between these molecules and solid bodies. The following are some of the phenomena:

When a body is placed in a liquid which wets it, for example, a glass rod in

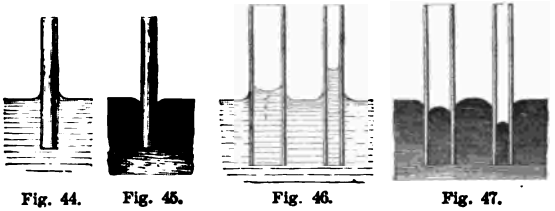


Fig. 44. Fig. 45. Fig. 46. Fig. 47.

water, the liquid is raised against the sides of the solid, and its surface, instead of remaining horizontal, becomes slightly concave (Fig. 44). If, on the contrary, the solid is one which is not moistened by the liquid, as glass by mercury, the liquid is depressed against the sides of the solid, and assumes a convex shape (Fig. 45). When a tube of fine bore is placed in a liquid, these phenomena become more manifest; and, according as the tubes are, or are not, moistened by the liquid, an ascent or a depression of the liquid is produced; and this is greater in proportion as the diameter of the tube is less (Figs. 46 and 47).

112. When two bodies of any given shape are dipped in water, similar capillary phenomena are produced, provided the bodies are sufficiently near.

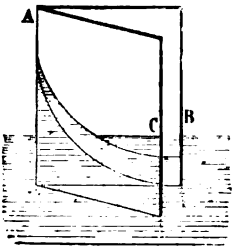


Fig. 48.

If, for example, two parallel glass plates are immersed in water, at a very small distance from each other, water will rise between the two plates in the inverse ratio of the distance which separates them. The height of the ascent for any given distance is half what it would be in a tube the diameter of which is equal to the distance between the plates. If immersed in mercury, a corresponding depression takes place. In Fig. 48, A B and A C represent two glass plates inclined to each other at a small angle, and immersed in water. The surface of the water within assumes the form of a regular curve.

113. Cause of Capillary Attraction.—The form of the surface of a liquid in contact with a solid depends on the relation between the attraction of the solid for the liquid, and of the mutual attraction between the molecules of the liquid.

Let *m* be a liquid molecule (Fig. 49) in contact with a solid. This molecule is acted upon by three forces: by gravity which attracts it downward, in the direction of the line *m* P; by the attraction of the liquid F, which acts in the direction *m* F; and by the attraction of the plate *n*, which acts in the direction *mn*. The resultant must be in one of three directions, according to the relative intensities of these forces: 1. In the direction *m* R (Fig. 49), when the sur-

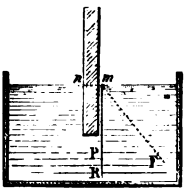


Fig. 49.

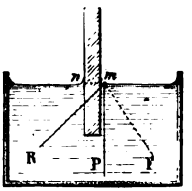


Fig. 50.

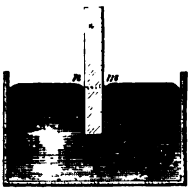


Fig. 51.

face *m* must be plane and horizontal; 2. If the force *n* increases, or F diminishes, the resultant R is within the angle *nm* P (Fig. 50); in this case the surface taking a direction perpendicular to *m* R, according to the law of the equilibrium of liquids, becomes concave; 3. If the force F increases, or *n* diminishes, the resultant R takes the direction *m* R (Fig. 51), within the angle P *m* F, and the surface becomes convex.

The elevation or depression of a liquid in a capillary tube depends on the concavity or convexity of the surface, caused as above described. For when concave, as in Fig. 52, the liquid molecules are sustained in equilibrium by the

forces acting on them, and they exercise no downward pressure on the inferior layers; while, by molecular attraction, they act on the nearest layers beneath them. Hence, when the surface is concave, the pressure on any layer, *mn*, within the tube, is diminished, and the liquid must rise until the internal pressure on the layer *mn* is equal to the external pressure *op*, acting on the same layer. When the surface is convex, as represented in Fig. 53, the reverse is the case; the pressure on the layer *mn* is greater than if the space *ghik* were filled,

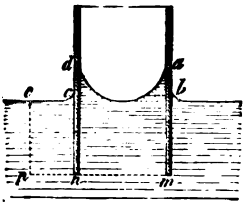


Fig. 52.

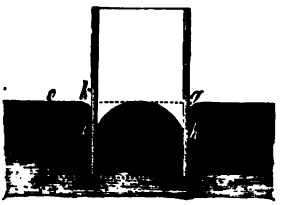


Fig. 53.

for the molecular forces are more powerful than gravity; hence, the liquid sinks in the tube until the internal pressure on a layer, as *mn*, is equal to the external pressure *op* on the same layer.

114. The **free surface** of a liquid is that which is bounded by a gas or by a vacuum; it has greater cohesion than any layer of the liquid in the interior.

For the particles at the surface are attracted by the adjacent particles in all directions, except in that above the surface. The attractions acting laterally compensate each other; and as there are no attractions above the surface to counteract those acting from below, the effect will be to lessen the mobility of particles on the surface, the result being the same as if the surface layer exerted a pressure on the interior. This *surface tension* increases with the cohesion of the liquid, and depends on the form of the surface.

A drop of mercury on a table has a spherical shape, because the molecular attraction is greater than gravity; and when the quantity is increased, the shape is spheroidal, retaining at its edge the convex form. A needle, if gently placed on the surface of water, will not sink, because its surface being covered with an oily layer, does not become wet, while its weight causes a concavity, the surface tension of which acts in opposition to the weight. On this principle, insects move on the surface of water.

Capillary Phenomena.—It is by capillary attraction that oil ascends in the wicks of lamps, that water rises in wood, sponge, paper, sugar, and in all bodies which possess pores of perceptible size. In the cells of plants the sap rises with great force, for the vessels are of very small bore.

A liquid does not overflow in a capillary tube, although the latter may be shorter than the liquid column which would otherwise be formed in it; for when the liquid reaches the top of the tube, the upper surface, though previously con-

cave, becomes convex, and as the downward pressure becomes greater than if the surface were plane, the ascending motion ceases.

IV.—ENDOSMOSE AND EXOSMOSE.

115. When two different liquids are separated by a thin porous partition, either organic or inorganic, a current sets in from each liquid to the other. To these currents—the one from within and the other from without—the names *endosmose* and *exosmose* are respectively given. The same phenomena are seen in a high degree in the case of gases.

These terms, signifying *impulse from within* and *impulse from without*, were employed by Dutrochet, who first drew attention to the phenomena. The general phenomenon may be termed *diosmose*, and may be illustrated by an instrument called the *endosmom'eter*. This consists of a long tube at the end of which a membranous bag is firmly bound (Fig. 54). The bag is filled with a strong syrup, or some other liquid denser than water, such as milk or albumen, and is then immersed in water. The liquid is seen to rise in the tube, while the outside level is lowered; and the external liquid is found to contain some of the liquid with which the bag was filled, showing the two opposite currents. The flow of the liquid toward that which increases in volume is endosmose, and the other exosmose. If water is placed in the bag, and immersed in the syrup, endosmose is produced from the water toward the syrup. In general, endosmose takes place toward the denser liquid; but to this alcohol and ether are exceptions.



Fig. 54.

The liquids used must be such as will mix; there can be no diosmose, for instance, with water and oil. They must, also, be of different densities; and one of them at least must be able to pass through the membrane. The well-known fact that diluted alcohol kept in a porous vessel becomes concentrated is due to endosmose. If a mixture of alcohol and water is kept for some time in a bladder, the volume diminishes, the alcohol becoming more concentrated; because, doubtless, the bladder permits the diosmose of water rather than of alcohol. Diosmose plays a most important part in organic life; the cell walls are membranes through which endosmose and exosmose take place.

V.—DIFFUSION OF LIQUIDS.

116. If oil be poured on water, no tendency to intermix is observed, separate layers of the two liquids being formed soon after agitation; but, if alcohol, which is specifically lighter, be poured upon water, the liquids gradually intermix, notwithstanding the difference in their specific gravities. This is called *diffusion*.

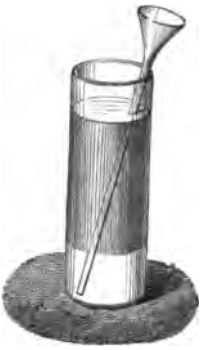


Fig. 55.

This phenomenon may be illustrated by the experiment represented in Fig. 55. A tall jar contains water colored by dissolving in it blue litmus. By means of a funnel some dilute sulphuric acid is carefully poured in, so as to form a layer at the bottom. The color of the solution will be gradually changed into red, progressing upward, proving that the acid has diffused itself throughout the entire mass.

VI.—WATER POWER.

117. **Water-wheels.**—When water is continuously flowing from a higher to a lower level, it may be used as a motive power. This power is utilized by means of water-wheels, which are wheels provided at the circumference with buckets, or float-boards, on which the water acts by pressure or by impact.

118. Water-wheels turn in a vertical plane round a horizontal axis, and are of two principal kinds: *undershot* and *overshot wheels*.

119. **Undershot wheels** are those in which the float-boards are at right angles to the circumference of the wheel, the lowest being immersed in the water.

120. **Overshot wheels** have on their circumference buckets of a peculiar shape, so made that the water may fall into them and move the wheel by its weight, each bucket, as it reaches the lowest point of its revolution, discharging its contents.

Undershot wheels are used when the quantity of water is great, with but little fall; overshot wheels are used when there is a smaller quantity of water, but a high fall, as in small mountain streams.

When the water is made to flow against the circumference of the wheel below the axis, it is called a *breast wheel*. This is often the most convenient and effective form that can be used.

VII.—PHENOMENA OF JETS.

121. **Velocity of Efflux.**—The velocity with which a liquid flows from an orifice in any part of the containing vessel is the same as a body would acquire in falling from a state of rest from a height equal to the distance between the surface of the liquid and the orifice.

This is called Torricelli's theorem, having been discovered by him. Thus, if there is an aperture in the bottom of a vessel, a particle at the surface of the liquid falling freely must have a velocity on reaching the orifice equal to that of any other body falling through the same distance. It follows from this that the velocity of efflux depends on the depth of the orifice below the surface, and not on the nature of the liquid; also that the velocities of efflux are directly proportional to the square roots of the depths of the orifices. That is, water would issue from one orifice 100 inches below the surface with ten times the velocity that it would issue from one only an inch below it.

122. **Direction of Jet.**—A liquid in passing from an orifice in the side of a vessel, describes a curve of the same character as the path of a projectile (81).

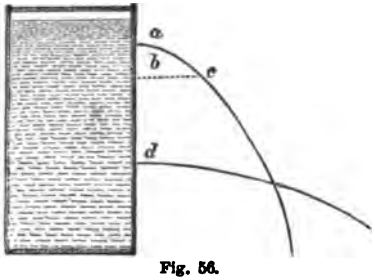


Fig. 56.

This is a result of Torricelli's theorem. Since the pressure is equal in all directions, water issues from an orifice in the side of a vessel with the same velocity as from an aperture in the bottom of the vessel at the same depth. Each particle of a jet issuing from the side of a vessel begins to move horizontally with the velocity above mentioned, but is drawn downward at every point by the force of gravity, producing the same effect as on the projectile, the path of which is a *parabola* (Fig. 56). This curve takes different forms according to the location of the orifice.

123. **Height of the Jet.**—A jet issuing from an orifice in a vertical direction, and having the same velocity as a body would have if it fell from a certain height, would reach the same height, if it were not prevented by the fall of the liquid particles, together with friction and the resistance of the air.

If the jet be inclined at a small angle, it will reach about nine-tenths of the theoretical height.

SYNOPSIS FOR REVIEW.

LIQUIDS.

I.—HYDROSTATICS: { 1. Hydrostatics. 2. Hydrodynamics. 3. Hydraulics. } Definition of each.

1. *Compressibility of Liquids:* { 1. As compared with gases. 2. Shown by the piezometer.
2. *Pressure of Liquids:*
 1. Equality of: { 1. Law of. 2. Illustration of. 3. Result of.
 2. Relation to depth of vessel.
 3. On the side of vessel.
 4. Hydrostatic paradox.
3. *Equilibrium of Liquids:*
 1. In a single vessel: { 1. Conditions of rest. 2. Illustration.
 2. In several communicating vessels.
 3. Of liquids of different density. (Phial of four elements.)
 4. Instruments: { 1. Hydraulic press. 2. Water level. 3. Spirit level.
 5. Artesian wells.
4. *Pressure on Immersed Bodies.* (Principle of Archimedes.)
5. *Pressure on Floating Bodies.*

II.—SPECIFIC GRAVITY:

1. *Definition and Standard.*
2. *Method of finding Specific Gravity:* { 1. Of solids. 2. Of liquids.

III.—CAPILLARY ATTRACTION:

1. *Definition.*
2. *Capillary Phenomena:* { With tubes. With glass plates.
3. *Causes.*

IV.—ENDOSMOSE AND EXOSMOSE:

1. *Definitions:* { 1. Endosmose. 2. Exosmose. 3. Diosmose.
2. *Conditions of Action.*

V.—DIFFUSION OF LIQUIDS:

Definition. Illustration.

VI.—WATER POWER:

Water Wheels: { 1. Undershot. 2. Overshot. 3. Breast. } { 1. How constructed. 2. When used.

VII.—PHENOMENA OF JETS:

1. *Velocity and Effect.* (Torricelli's theorem.)
2. *Direction of Jet.*
3. *Height of Jet.*

APPLICATION OF PRINCIPLES.

Explain the following phenomena: 1. Why oil, that floats on water, will sink in alcohol. 2. Why corpulent persons swim more easily than others. 3. Why the water at the bottom of the ocean is more dense than at the surface. 4. Why a vessel draws more water in a river than on the ocean. 5. Why a pound of iron occupies more space than a pound of gold. 6. Why iron will not sink in mercury. 7. Why a solid body feels lighter when immersed in water. 8. Why cream rises to the surface of milk. 9. Why writing-paper needs to be sized. 10. Why blotting-paper absorbs ink. 11. Why, when one corner of a lump of sugar is dipped in water, the whole mass becomes saturated with it. 12. Why a board shrinks when dried, and a woolen cloth when wet. 13. How a plant is watered by pouring water into the saucer of the flower-pot. 14. Why quicksilver will not wet a piece of board when poured upon it, but rolls off in spheroidal drops. 15. How the wick of a lamp is supplied with oil. 16. Why clothes-lines are tightened by wetting them. 17. Why the cork of a bottle is driven in when the bottle is sunk to a great depth in the ocean. 18. Why gold when plunged into quicksilver becomes covered with it. 19. Why a greased needle will float on the surface of water. 20. How the sap of a tree is drawn from the root to the branches and leaves. 21. Why rubber toy balloons after a certain time lose their buoyancy. 22. Why a body immersed in water loses a part of its weight. 23. Why the weight lost is equal to that of a quantity of the liquid of the same bulk. 24. Why the discharge of water from the orifice of a vessel is increased by heating the water. 25. Why alcohol will mix with water, although lighter. 26. Why a bottle filled with alcohol, and tightly closed with a piece of bladder, when immersed in water, loses the alcohol and receives water. 27. Why a block of stone may be split by driving wooden wedges into a groove of it, and wetting them. 28. Why ink poured on the edges of the leaves of a book will penetrate farther into the book than if poured upon the surface of the leaves.

PROBLEMS FOR EXERCISE.

1. What is the pressure upon the bottom of a cistern 6 feet square and 10 feet deep, when it is three-fifths filled with water?

2. What is the pressure on the side of the cistern, 4 feet from the bottom?

3. What is the total pressure on the side when the cistern is full?

4. A barrel, 3½ feet high, each end of which contains 5½ square feet, has a vertical tube, 5½ feet high and three-quarters of a square inch in area at the end, connected with the head. If the barrel and tube are both filled with water, what is the pressure on the bottom of the barrel?

5. A cylindrical vessel 9 inches high, the bottom of which has an area of 10½ square inches, is filled with sulphuric acid. What is the pressure on the bottom?

6. A solid substance weighing 61.25 grains being placed in a vessel full of water, caused an overflow of 8.75 grains of water. What was the specific gravity of the substance?

7. If a solid weighing 750 grains in air, weighs 630 grains in water, what is its specific gravity?

8. A body loses 30 grains in fresh water, what will it lose in sea-water, the specific gravity of which is 1.026?

9. If a body loses 23 grains in water, 21 grains in oil, and 18½ grains in alcohol, what is the specific gravity of the oil and alcohol?

10. A piece of platinum (rolled) weighs 2⅛ ounces in air and 47¾ pennyweights in water, what will be its weight in mercury?

11. A cube of lead, the side of which is 2 inches, is to be supported in water by being suspended to a cube of cork. What must be the length of a side of the latter, its specific gravity being 0.25, while that of the lead is 11.35?

12. The force with which a hydraulic press is worked is 20 pounds: the arm of the lever on which this force acts is 5 times as long as that of the resistance; lastly, the arm of the large piston is 70 times that of the smaller one. Required the pressure transmitted to the large piston.

13. A substance weighs 9 ounces, but when attached to a pound of lead, the two together weigh in water 13⅛ ounces. What is the specific gravity of the substance, that of the lead being 11.35?

14. What would be the weight of a cubical piece of silver 5 inches each side (specific gravity 10.5)?

15. Suppose a vault 5 feet high, 6 feet long, and 3 feet wide were filled with gold, what would be the weight of the gold?

16. What would a flask of ether containing 27½ cubic inches weigh, the flask itself weighing 1 ounce?

17. One of the branches of a U-shaped glass tube contains mercury to the height of 3½ inches, while the other contains a different liquid to the height of 9¼ inches, the two columns being in equilibrium. Required the density of the second liquid as compared with mercury and with water.

18. What pressure does the body of a diver sustain at a depth of forty-five feet, if the superficial area of his body is 23½ square feet?

19. A piece of iron, weighing 3 pounds, is attached to a piece of wood which weighs 5 pounds; and the weight of both in water is found to be 7⅛ pounds. What is the specific gravity of the wood, that of iron being 7.21?

20. A piece of lead that weighs 120 grains, is found to lose a weight of 10½ grains in water, and 8¼ grains in alcohol. What is its specific gravity, and the specific gravity of alcohol?

CHAPTER IV.

GASES.

I.—PROPERTIES OF GASES.

124. **Gases** are bodies the molecules of which are in a constant state of motion, in virtue of which they possess the most perfect mobility, and are continually tending to occupy a greater space. This tendency causes the property known as *expansibility, tension,* or *elastic force;* on account of which gases are often called *elastic fluids.* That department of physics which treats of gases is called *pneumatics.*



Fig. 57.

The properties of liquids and gases differ rather in degree than in kind. In both, the particles move easily among themselves; both are compressible, though in very different degrees. The property by which gases are distinguished from liquids is their tendency to indefinite expansion. Matter assumes the solid, liquid, or gaseous form, according to the relative strength of the cohesive and repulsive forces exerted by their molecules. In liquids, these forces balance each other; in gases repulsion preponderates.

By the aid of pressure and low temperature, the force of cohesion may be so increased in many gases as to convert them into liquids; and it is known that, with sufficient pressure and cold, all may be liquefied.

The *expansibility of gases* may be shown by the following experiment: A bladder closed by a stop-cock and about half full of air, is placed under the receiver of an air-pump (Fig. 57), and the air being withdrawn, the bladder is immediately distended, showing the tendency of the air within to expand when the pressure of the external air is withdrawn. When air is admitted into the receiver, the bladder collapses again.

The *compressibility of gases* is readily shown by the *pneumatic syringe* (Fig 58). This consists of a stout glass tube closed at one end, and provided with a tight-fitting solid piston. When the rod of the piston is pressed, the air becomes compressed in the tube, but regains its former volume as soon as the force is withdrawn.

The *weight of gases* can be shown by means of a glass globe of the capacity of three or four quarts, the neck being provided with a stop-cock, which closes it tightly, and by which it can be screwed to the plate of the air-pump. The globe is first exhausted of air, and then weighed; and is again weighed after



Fig. 58.

the air is allowed to enter. The difference of weight will obviously show the weight of the air. By this method it has been found that 100 cubic inches of dry air, under the ordinary atmospheric pressure, and at the temperature of 61° F., weighs 31 grains. The same volume of carbonic acid gas, under the same conditions, weighs 47.25 grains; and the same quantity of hydrogen, the lightest of all gases, weighs 2.14 grains.

II.—THE ATMOSPHERE.

125. The **atmosphere** is the layer of air which surrounds our globe. It partakes of the rotary motion of the globe, but has its equilibrium constantly disturbed by local circumstances that produce currents, called winds. It is essentially a mixture of oxygen and nitrogen gases, in the proportion of about four parts of nitrogen to one part of oxygen.

More exactly stated, the composition of the atmosphere is as follows:

Nitrogen	78.49
Oxygen	20.63
Aqueous vapor	0.84
Carbonic acid	0.04
	100.00

The carbonic acid arises from the respiration of animals, from combustion, and the decomposition of organic substances; and there must be, therefore, an enormous production of it. Yet the composition of the atmosphere does not

vary, for plants in the process of vegetation decompose the carbonic acid into carbon and oxygen, making use of the former and restoring the latter to the air.

126. The **pressure of the atmosphere** on a given unit of area is constant at the same level, being equal to the weight of the column of atmosphere above that level resting on that unit of area, diminishing as we ascend, and increasing as we descend from that level.



Fig. 59.

In consequence of the expansive force of air, it might be supposed that the molecules would pass off into the planetary spaces; but as its expansive force constantly decreases, an equilibrium is reached, at a certain height, between this expansive force and gravity, beyond which no further expansion can take place.

The phenomenon of twilight, which ceases when the sun is 18° below the horizon, shows that at the height of 45 miles the atmosphere is not dense enough to reflect the rays of the sun; and at 60 miles, it is assumed by some, its limit is reached. On the other hand, meteorites, whose luminous appearance is due to the friction of the air, have been seen at a height of 200 miles, and observations made at Rio Janeiro by M. Liais indicate a height of from 198 to 212 miles.

The pressure of the atmosphere may be shown by the following experiment: On one end of a stout glass cylinder (Fig. 59) about 5 inches high and open at both ends, a piece of bladder is tied quite air-tight. The other end, the edge of which is ground and well greased, is pressed on the plate of the air-pump. As soon as the air in the vessel is rarefied, by working the air-pump the bladder is depressed by the weight of the atmosphere above it, and finally bursts with a loud report, caused by the force of the pressure.



Fig. 60.



Fig. 61.

The *Magdeburg hemispheres*, invented by Otto von Guericke, of Magdeburg, illustrate the same fact. The apparatus consists of two hollow brass hemispheres of about 4 inches in diameter, the edges being made to fit tightly (Figs. 60 and 61). One of them is provided with a stop-cock, by which it can be screwed on the air-pump, and the other with a handle. As long as the hollow globe formed by uniting them contains air, they can be easily separated, since the external pressure of the atmosphere is counterbalanced by the elastic force of the air within; but when the air is withdrawn, the hemisphere cannot be separated but with great difficulty, showing the pressure of the air upon the outer surface.

127. The **amount of pressure** of the atmosphere is equal to that of a column of mercury 30 inches in height, or about 15 pounds on every square inch.

This fact, showing the exact weight of the atmosphere, was ascertained by Torricelli, a pupil of Galileo, in 1643, by the following simple experiment: A glass tube about a yard long and a quarter of an inch in internal diameter (Fig. 62), sealed at one end, is filled with mercury. The aperture C being closed by the thumb, the tube is inverted, the open end plunged into a trough of mercury, and the thumb removed. The tube being in a vertical position, the column of mercury sinks, and comes to rest at a certain height, A, which, at the sea-level, is found to be about 30 inches above the surface of the mercury in the trough. This represents the pressure of the atmosphere on the mercury in the trough; since, as there is a vacuum in the tube above the mercury, the pressure is not counterbalanced. If the upper end of the tube be opened, so as to admit air, the mercury will immediately sink to the outside level.

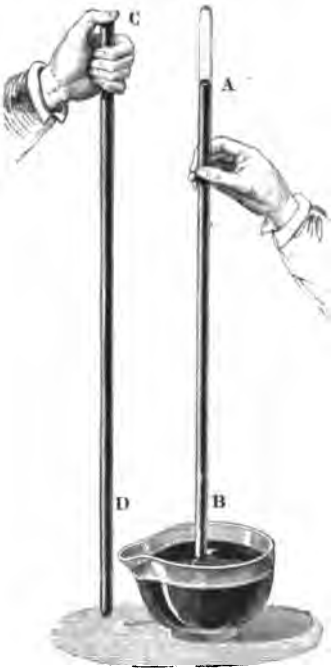


Fig. 62.

This being the case, the column of mercury in the tube should vary with the pressure of the atmosphere, which diminishes as we ascend above the surface of the earth. To test this, Pascal requested one of his relations to repeat Torricelli's experiment on the summit of Puy de Dome, in Auvergne; and the result was that the mercury stood about three inches lower, indicating a reduced pressure of the atmosphere at that height.

At about 3¼ miles from the surface of the earth, the mercury in the barometer falls to 15 inches, showing that half the air contained in the atmosphere is within that distance.

Pascal repeated Torricelli's experiment at Rouen, in 1646, with other liquids. Using a tube 50 feet long, he tried it with water, and found the supported column to be 34 feet high, that is, 13.6 times as high as mercury; and as mercury is 13.6 times as heavy as water, the columns must be of the same weight, and the supporting force must be the same.

The pressure of the atmosphere on each square foot must, obviously, be equal to 30 cubic inches of mercury, each of which weighs about 0.49 of a pound; hence the entire pressure must be $0.49 \times 30 = 14.7$ pounds, on every square inch, or 144 times that, equal to about one ton on every square foot. A gas or liquid which acts in such a manner as to exert a pressure of 15 pounds on every inch of surface, is said to exert a pressure of *one atmosphere*. If, for example, the elastic force of steam in a boiler is equal to 90 pounds (6×15), we speak of it as a pressure of six atmospheres.

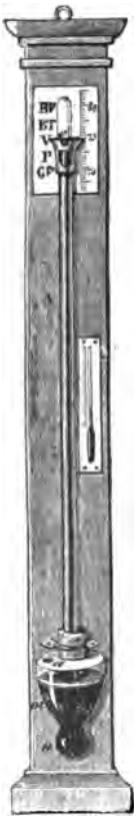


Fig. 63.

The surface of the body of a man of medium size is about 16 square feet, or 2,304 square inches; and $2{,}304 \times 15 = 34{,}560$; hence a man supports on the surface of his body a pressure of nearly 17 tons. This is insensible, because it is counteracted at every point by equal pressures; since every part of the body is filled with air. When the external pressure is removed from any part of the body, either by a cupping vessel or by the air-pump, the pressure from within shows itself by the distention of the surface.

III.—THE BAROMETER.

128. The **barometer** is an instrument used for measuring the pressure of the atmosphere.

In ordinary barometers, the pressure is measured by the height of a column of mercury, as in Torricelli's experiment; but there are barometers without any liquid, one of which (the aneroid) is remarkable for its simplicity and portability.

The *cistern barometer* consists of a straight glass tube closed at one end, about 33 inches long, filled with mercury, and dipping into a cistern containing the same metal.

In order to render the instrument more portable, and the variations of the level in the cistern less perceptible when the mercury rises or falls in the tube, several different forms have been constructed. Fig. 63 represents one form of the cistern barometer. The apparatus is fixed to a mahogany stand, on the upper part of which there is a scale graduated in inches from the level of the mercury in the cistern. A movable index, *i*, shows the level of the mercury, and a thermometer on one side indicates the temperature. In this construction the zero of the scale does not always correspond to the level of the mercury of the cistern.

129. The **siphon barometer** is a bent glass tube, one of the branches of which is much longer than the other. The longer branch,

which is closed at the top, is filled with mercury, as in the cistern barometer; while the shorter branch, which is open, serves as a cistern. The difference between the two levels is the height of the barometric column.

This barometer, as modified by Gay-Lussac, is represented in Fig. 64. To render it more portable, he joined the two branches by a capillary tube; so that, when the instrument is inverted, the tube always remains full in consequence of the capillarity, and air cannot penetrate into the longer branch. The shorter branch is closed, but there is a capillary aperture in the side, *a*, through which the atmospheric pressure is transmitted. The barometric height is determined by means of two scales, which have a common zero at O, toward the middle of the longer branch, and are graduated in contrary directions, the one from O to E, and the other from O to B, either on the tube itself, or on brass rules fixed parallel to the tube. The total height of the barometric column, AB, is the sum of the distance from O to A, and from O to B.



Fig. 64.

The space at the top of the tube, which is called the *Torricellian vacuum*, must be free, not only from air, but from aqueous vapor; and to produce this condition, a small quantity of pure mercury is placed in the tube and boiled for some time. It is then allowed to cool, and a further quantity, previously warmed, is added, which is boiled; and so on, until the tube is quite full. In this manner, the moisture and the air which adhere to the sides of the tube pass off with the mercurial vapor.

130. The height of the barometric column undergoes constant variations, not only from day to day, but during the same day, which are caused by the expansion or contraction of the air, and its consequent change in density.

If the temperature of the whole atmosphere were the same, no currents would be produced, and at the same height the pressure would be the same; but as one part becomes warmer than the neighboring parts, it rises, and the pressure is diminished. In indicating these changes, the barometer becomes a *weather glass*; for in fine weather the mercury rises, and falls when there is rain, snow, wind, or storm, or when a storm is about to occur. Watery vapor being lighter than air, the presence of large quantities of it reduces the pressure of the atmosphere.

The *wheel barometer*, which was invented by Hooke, is a siphon barometer, and especially intended to indicate these changes in the weather (Fig. 65). In the shorter leg of the siphon there is a float which rises and falls with the mercury (Fig. 66). A string attached to this float passes round a pulley, O; and at the other end there is a weight, P, somewhat lighter than the float. A needle fixed to the pulley moves round a graduated circle, on which

are marked the words used to indicate the different states of the weather. When the pressure varies, the float sinks or rises, and moves the needle round to the corresponding points on the scale.

131. **Determination of Heights.**—Since the pressure of the atmosphere diminishes as we ascend from the surface of the earth, the barometer becomes a means of determining the difference be-



Fig. 65.



Fig. 66.



Fig. 67.

tween the heights of two stations, such as the base and summit of a mountain.

The instrument chiefly used for this purpose is the *aneroid barometer* (Fig. 67), which derives its name from the Greek *a*, without, and *nēros*, moisture, from the fact that no liquid is used in its construction. It is, therefore, quite portable, and can be constructed of such delicacy as to indicate the difference in pressure and height between the ground and an ordinary table. It consists of a cylindrical metal box, exhausted of air, the top being made of thin corrugated metal, so elastic that it yields to the slightest pressure of the atmosphere. When

this increases, the top is pressed inwards; when it diminishes, the elasticity of the lid, aided by a spring, tends to move it in the opposite direction. These movements are transmitted, by delicate multiplying levers, to an index which moves on a scale.

IV.—LAW OF THE COMPRESSIBILITY OF GASES.

132. **Mariotte's Law.**—The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure which it bears; that is, for the same temperature, the density of a gas is proportional to its pressure.

This law of the compressibility of gases was discovered by Boyle in 1662, and afterwards independently by Mariotte in 1679. Hence, in England it is called "Boyle's law." It may be verified by an apparatus contrived by Boyle (Fig. 68). It consists of a long glass tube fixed to a vertical support and open at the upper part, the other end, which is bent into a short vertical leg, being closed. On the shorter leg there is a scale which indicates equal capacities; the scale against the long leg gives the heights. The zero of both scales is in the same horizontal line. A small quantity of mercury is poured into the tube, so that its level in both branches may be at zero; this puts the air in the short leg under the pressure of the atmosphere, exerted through the open tube. Mercury is then poured into the longer tube until the volume of the air in the shorter tube is reduced one-half—from 10 to 5; the height of the mercurial column, CA, will then be found exactly equal to that of the barometer at the time of the experiment, showing that the pressure is equal to one atmosphere, which makes a pressure of two atmospheres on the air in the shorter leg. Thus, by doubling the pressure the volume of the air has been diminished to one-half.

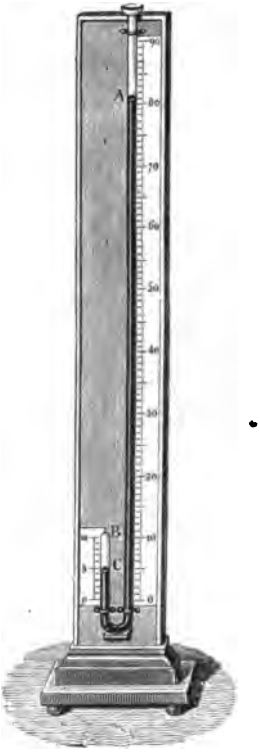


Fig. 68.

The law can be verified in different ways by varying the experiment as to the amount of pressure. Since water is seven hundred and seventy-three times as heavy as air, under a pressure of seven hundred and seventy-three atmospheres air would be as dense as water. Beyond a certain amount of pressure, however, Mariotte's law is only approximately true. It has been shown that air does not exactly follow this law, its compressibility increasing with the pressure. This is true also, to some extent, of nitrogen, carbonic acid, and hydrogen.

V.—PRESSURE UPON BODIES IN AIR.

133. When bodies are immersed in gases, the pressure exerted upon them is transmitted equally in all directions, so that, as in the case of bodies in liquids, they lose a part of their weight equal to that of the air which they displace.

The principle of Archimedes is thus equally true for bodies in air and for those in water. When a body is heavier than air, it will sink; if no heavier, it will float; if lighter, the body will rise in the atmosphere until it reaches a layer of the same density as itself; and the force of its ascent will be equal to the excess of the buoyancy over the weight of the body. This is the reason why smoke, vapors, clouds, and balloons rise in the air.

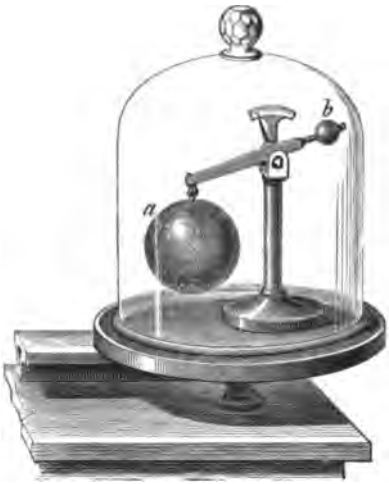


Fig. 69.

An instrument called the *baroscope* (Fig. 69) is used to demonstrate the loss of weight in air. It consists of a scale-beam, at one end of which there is a small leaden weight, and at the other a hollow copper sphere, so adjusted that in the air they exactly balance each other. When they are placed under the receiver of the air-pump and the air withdrawn, the sphere sinks, showing that it is in fact the heavier, having previously been supported by the air. To prove that the loss of weight is equal to the weight of the displaced air, suppose the volume of the sphere to be 10 cubic inches, the weight of which volume of air is 3.1 grains; then, if that weight be added to the leaden weight, it will overbalance the sphere in air but exactly balance it in a vacuum.

134. Air-balloons are hollow spheres made of some light material, which, when they are filled with heated air or hydrogen gas, rise in the air on account of their relative lightness.

Balloons were invented by the brothers Mongolfier, who made their first experiment in France, in 1783, using a balloon forty yards in circumference, and weighing 500 pounds. At the lower part there was an aperture, and a sort of boat was suspended in which there was a fire to heat the internal air. This balloon rose to the height of 2,200 yards. Hydrogen gas was substituted for hot air, being much safer. Gay-Lussac, in 1804, attained in his balloon a height of 23,000 feet, at which altitude the barometer indicated only 12.6 inches, and the thermom-

eter a temperature of 16°, while on the ground it was 88°. The circulation of the blood and the respiration were greatly accelerated, Gay-Lussac's pulse making 120 pulsations a minute instead of 66. The sky also had a very dark blue tint. In 1862, Mr. Glaisher, ascending from Wolverhampton, in England, attained the greatest height ever reached, more than 36,000 feet. The barometer

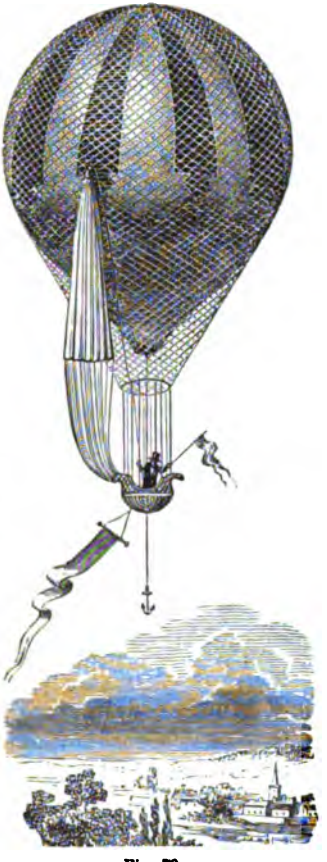


Fig. 70.



Fig. 71.

indicated less than 10 inches at the altitude of 29,000 feet, and the mercury in the thermometer descended nearly to zero. Balloons have been used in military reconnoitering (Fig. 70).

A balloon is made by sewing long bands of silk together, and is rendered air-tight by a coating of varnish. At the top there is a safety-valve closed by a spring, which the aëronaut can open at pleasure by means of a cord, and thus

limit the ascent of the balloon by letting out the gas. By throwing out ballast—usually bags of sand—he causes the balloon to rise. The car is formed of light wickerwork, and is suspended by cords to the network which covers the balloon. Hydrogen or coal gas is used for inflating it. A grappling-iron suspended to the car is employed to accomplish the descent. By this the balloon becomes anchored to some object on the surface of the ground, and the balloon is lowered by pulling on the rope attached to the anchor.

The balloon, of course, ascends until it reaches a height at which the buoyancy of the air is equal to the weight of the balloon, and then the latter is carried along by the currents of the atmosphere. The aëronaut determines the height which he has reached by observing the mercury in the barometer. A long flag attached to the car indicates by its position whether he is rising or falling.

An ordinary balloon, capable of carrying three persons, is 50 feet high and 100 feet in circumference in the middle, and contains about 20,000 cubic feet. Such a balloon would weigh about 250 pounds, while the car, rope, and ballast would weigh from 100 to 150 pounds.

135. The **parachute** is a contrivance to allow the aëronaut to leave the balloon by giving him the means of descending slowly to the ground.

It consists of a large circular piece of cloth, about 16 feet in diameter, and which by the resistance of the air is made to spread out, as it descends, like a huge umbrella. In the center there is an aperture, through which the air compressed by the rapidity of the descent partially makes its escape, thus preventing dangerous oscillations (Fig. 71). In Fig. 70 there is a parachute attached to the network of the balloon by means of a cord which passes round a pulley, and is fixed at the other end to the boat or car. When the cord is cut the parachute sinks, at first very rapidly, but more slowly as it spreads open, as shown in the figure.

VI.—AIR-PUMP AND OTHER APPARATUS.

136. The **air-pump** is an instrument used to withdraw air from any given space. By its means, however, the air can only be indefinitely rarefied, as an absolute vacuum cannot be produced.

So great a rarefaction of the air can be effected by the air-pump, that it practically amounts to a vacuum. This instrument was invented by Otto von Guericke in 1650, soon after the invention of the barometer. Its construction is shown in Fig. 72. E, the receiver in which the vacuum is to be produced, is a bell glass resting on a plate, V, of thick glass ground perfectly smooth. In the center of V, at *n*, there is an opening by which a communication is made between the interior of the receiver and of the cylinders P, P. This communication is effected by a tube or pipe passing through the body of the plate T, and then branching off at right angles, and connecting with the cylinders P, P, which are commonly of glass and firmly cemented to the plate T, and in which are two

pistons moving air-tight. Each piston is moved by a rack, working with a pinion, which is turned by the handles M N, so that when one piston is raised the other is depressed. Each cylinder is fitted with a valve so contrived that, when its piston is raised, communication is opened between the receiver and the cylinder, and closed when the piston is depressed. Thus when the piston is raised, the air in the receiver expands so as to fill both receiver and cylinder; and when it is depressed, instead of being forced back into the receiver, it

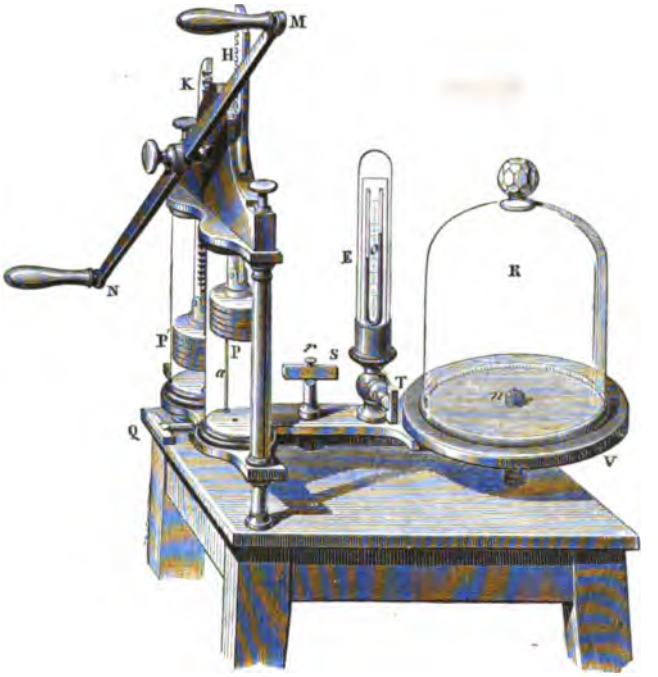


Fig. 72.

escapes, through the valve in the piston, into the open air, and thus the quantity of air in the receiver is diminished. This, however, owing to its elasticity, fills the whole space, and consequently a rarefaction takes place, which is increased at every stroke of the pump. The location of the valves and the action of the pistons will be seen in Fig. 73.

It is clear that as the rarefaction increases the pressure on the pistons becomes very great, but the pressure on one is very nearly balanced by that on the other, so that the experimenter has merely to overcome the difference of the two pressures. This is the reason that two cylinders are employed.

Theoretically, an absolute vacuum is impossible; for suppose the volume of

each cylinder is $\frac{1}{10}$ of that of the receiver, then the whole space must be $\frac{1}{10}$ of the receiver; and $\frac{1}{11}$ of the air is withdrawn at the first stroke; $\frac{1}{11}$ of the remainder at the second; and so on. Thus there will always be a remnant of air to be withdrawn. After a certain degree of rarefaction has been attained, the elastic force of the remaining air becomes too slight to open the valves, and the limit of the machine is reached. There are many different constructions of the air-pump.

137. **Uses of the Air-Pump.**—Several experiments requiring the use of the air-pump have already been referred to: the fall of bodies in a vacuum, the bursting of a bladder by the pressure of the

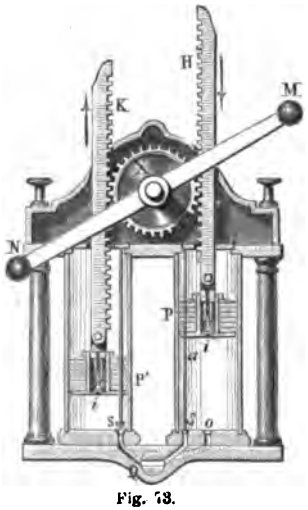


Fig. 73.



Fig. 74.

air, the Magdeburg hemispheres, and the baroscope. A few others are here described:

The *fountain in vacuo* (Fig. 74) is an experiment showing the elastic force of the air. It consists of a glass vessel, A, provided at the bottom with a stop-cock and a tubulure which projects into the interior. Having screwed this apparatus to the air-pump and exhausted it of air, the stop-cock being closed, it is placed in a vessel of water, R. On opening the stop-cock, the pressure of the air upon the water in the vessel makes it rise in the tubulure, and spout in the form of a fountain.

If we place a lighted taper under the receiver, the flame will become weaker and weaker as the air is rarefied, until it is extinguished. Mammalia and birds

soon die in the exhausted receiver; fish and reptiles live somewhat longer, and insects several days. This shows the dependence of combustion and life upon the oxygen of the air.

138. **Hero's Fountain,** which derives its name from its inventor, Hero, who lived at Alexandria 120 B.C., depends on the elasticity of the air.

It consists of a brass dish, D (Fig. 75), and of two glass globes, M and N. The dish communicates with the lower part of the globe N by a long tube, B; and another tube, A, connects the two globes. A third tube passes through the dish D to the lower part of the globe M. This tube having been taken out, the globe M is partly filled with water; the tube is then replaced, and water is poured into the dish. The water flows through the tube B into the lower globe, and expels the air, which is forced into the upper globe; the air being thus compressed, acts upon the water, which is, therefore, thrown out in a jet, as shown in the drawing. But for the resistance of the air and friction, the liquid would rise to a height above the water in the dish equal to the difference of level in the two globes.

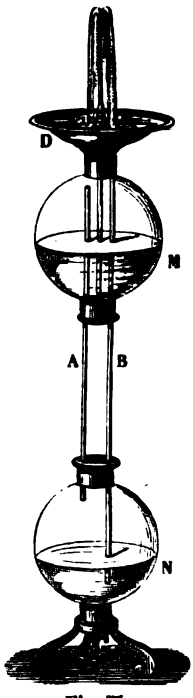


Fig. 75.

139. The **siphon** is a bent tube open at both ends, with unequal legs, and is used in transferring liquids from one vessel into another.

Being filled with some liquid, and the two ends being closed, the shorter leg is dipped into the liquid, as shown in Fig. 76; or the shorter leg having been dipped into the liquid, the air is exhausted by applying the mouth at B. A vacuum being thus produced, the liquid in C rises and fills the tube, and will run out through the siphon as long as the shorter end dips into the liquid. The continuous flow is caused by the difference in pressure at C and B. At the former it is the atmospheric pressure minus the column of liquid C D, and at the latter it is the atmospheric pressure minus A B; therefore the force acting at B is less than that at C, and the flow takes place, which will be more rapid in proportion to the difference of level between the two apertures.



Fig. 76.

140. **Pumps** are machines which serve to raise water either by suction, by pressure, or by both combined.

They are, therefore, divided into *suction* or *lift pumps*, and *suction and force pumps*.

141. The various parts entering into the construction of a pump are the barrel, the piston, the valves, and the pipes.

142. The *barrel* is a cylinder of metal or wood, in which the *piston* works. The latter is a metal or wooden cylinder wrapped with tow, and working with gentle friction the whole length of the barrel. The *valves* are discs of metal or leather, which alternately close the apertures connecting the barrel with the pipes.



Fig. 77.

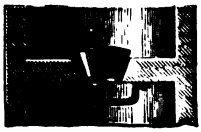


Fig. 78.

The most common valves are the *clack valve* (Fig. 77) and the *conical valve* (Fig. 78). The first is a metal disc fixed to a hinge on the edge of the orifice to be closed, the lower part being covered with thick leather. Sometimes it is wholly made of leather. The conical valve is a cone of metal made to fit into an aperture of the same shape, below which is an iron loop, through which passes a bolt-head fixed to the valve, so as to keep the valve in place.

143. The **suction or lift pump** is one that acts solely by atmospheric pressure.

A model of such a pump is represented in Fig. 79. It consists (1) of a *glass cylinder*, B, at the bottom of which there is a valve, S, opening upward; (2) of a *suction tube*, A, which dips into the reservoir from which water is to be raised; (3) of a *piston*, which is moved up and down by a rod worked by a handle, P. The piston is perforated by a hole, and the upper aperture is closed by a valve, O, opening upward. When the piston rises, a vacuum is formed below it, for the valve O is closed by the pressure of the air above it, while the air rising through the tube A to fill the vacuum opens the valve S. When the piston descends, the valve S is closed, and the air in the cylinder is forced through O, and escapes by the pipe C. In a few strokes the air is exhausted,



Fig. 79.

and the water rises (is sucked up) by atmospheric pressure on the surface of the water in the reservoir, provided the suction tube does not exceed 26 to 28 feet. The atmospheric pressure supports a higher column, but the vacuum in the barrel is not complete, because the piston does not exactly fit on the bottom of the barrel. When the water has passed the piston, it is raised by the ascending force of the latter, and the height to which it rises depends on the force with which the piston is moved.

144. The **suction and force pump** is a pump the action of which depends on both exhaustion and pressure.

In Fig. 80, at the base of the barrel, where it is connected with the tube A, there is a valve, S, which opens upward ; at *o* there is an aperture leading into

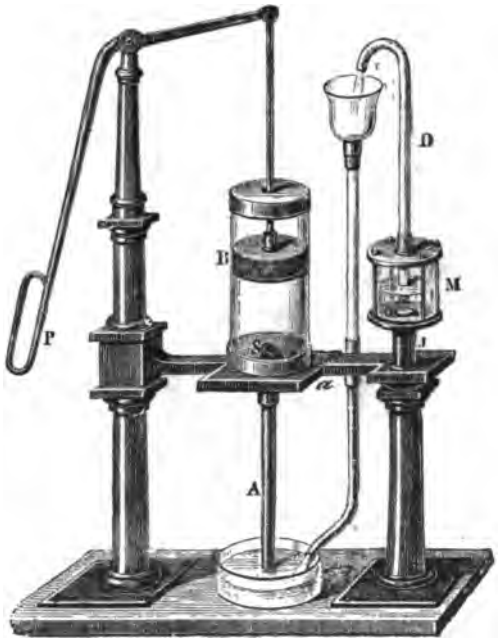


Fig. 80.

a pipe which communicates, through the upward valve O, with the *air-chamber* M, with which the tube D is connected. When the piston B, which is solid, rises, it forms a vacuum, and the water rises into the cylinder ; when it descends, the valve S closes, and the water is forced through *o* into the air-chamber, and the pressure of the air forces it up D in a continuous stream. Without the air-chamber, the stream would be intermittent, for the flow would cease at every ascent

of the piston B. But the pressure of the water on the air of the air-chamber causes a reaction which makes the flow continuous; since, when the force of the piston is withdrawn, the air reacts on the water and raises it in the tube D, until the next descent of the piston takes place.

In this kind of pump, the force required to raise the piston, when the pipe is filled to the spout, is equal to the weight of a column of water the height of which is equal to the vertical distance between the spout and the surface of the water in the reservoir, its base being equal to that of the piston.

145. The fire-engine consists of two force-pumps working alternately.

The two pumps *m* and *n* (Fig. 81), worked by the same lever P Q, are immersed in a tank which is kept filled with water as long as the machine is in

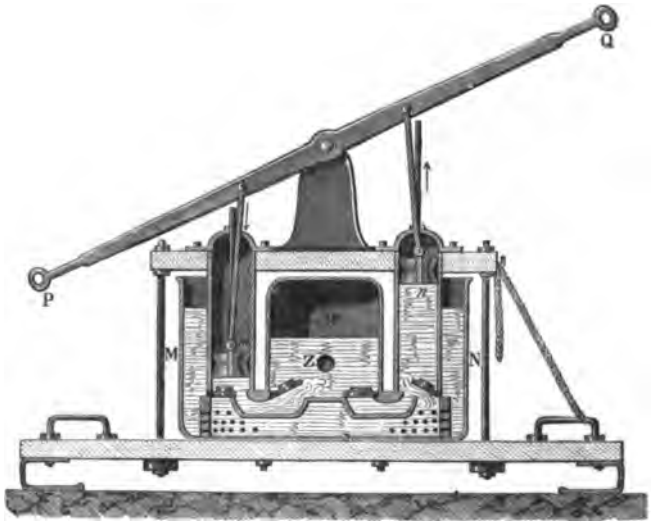


Fig. 81.

operation. When one pump, as *n*, draws water from the tank, the other, *m*, forces it into the *air-chamber* R, whence, by the orifice Z, it passes into the delivery tube, by which the stream can be turned in any direction. The air-chamber R acts as in the suction and force-pumps (Fig. 80), causing a continuous flow by the reaction of the air against the pressure of the water forced into it.

SYNOPSIS FOR REVIEW.

GASES.

I.—PROPERTIES OF GASES, OR ELASTIC FLUIDS.

1. *Expansibility.*
2. *Compressibility.*
3. *Weight.*

II.—THE ATMOSPHERE.

1. *Composition.*
2. *Extent.*
3. *Pressure.*
 1. How indicated. (Magdeburg hemispheres.)
 2. Amount. (Torricelli's tube.)

III.—THE BAROMETER.

1. *Construction:*
 1. Cistern barometer.
 2. Siphon barometer.
 3. Wheel barometer.
2. *Use:*
 1. As a weather glass.
 2. To determine heights.
3. *Aneroid Barometer.*

IV.—LAW OF COMPRESSIBILITY.

Mariotte's or Boyle's Law.
1. How illustrated.
2. How verified.
3. Exceptions.

V.—PRESSURE UPON BODIES IN AIR.

1. *Law of.*
 1. Baroscope.
 2. Principle of Archimedes.
2. *Balloons:*
 1. Invention of.
 2. Heights attained in.
 3. Phenomena observed in.
 4. Use of.
 5. Construction of.
3. *Parachute:*
 1. Construction of.
 2. Use of.

VI.—AIR-PUMP AND OTHER APPARATUS.

1. *Air-Pump:*
 1. Construction of.
 2. Vacuum produced by.
 3. Uses of.
2. *Fountain in Vacuo.*
3. *Hero's Fountain.*
4. *Siphon.*
5. *Pumps:*
 1. Suction or lifting.
 2. Suction and force.
 3. Fire-engine.
6. *Valves:*
 1. Clack.
 2. Conical.

APPLICATION OF PRINCIPLES.

Explain the following phenomena: 1. Why, in order to draw ale or cider from a barrel, there must be a vent-hole in the upper part. 2. The passage of the air into the lungs when the chest is expanded. 3. How the boy is able to lift a heavy stone with a leather-sucker. 4. Why the water flows continuously through a siphon. 5. Why the parachute descends slowly from a balloon. 6. Why a pump cannot be used to draw water from a well 50 feet deep. 7. Why the glass tube in a barometer must be more than 28 inches long. 8. A person pasted a piece of paper on the inside of the bottom of a tumbler, and plunged the tumbler vertically into a pail of water; and on taking it out, found the paper *dry*. 9. Why the surface of the skin is raised by a cupping-glass. 10. Why a tumbler being filled with water, and a piece of card placed over it, when the tumbler is carefully inverted, the water is held in by the card. 11. When a person sucks a fluid from a vessel through a straw, what force carries the fluid up the straw. 12. Why a fire-balloon rises in the air. 13. What the force is that drives the pellets from a pop-gun. 14. How the common syringe acts. 15. Why carbonic acid gas can be poured from one vessel into another. 16. Why hydrogen gas is used in balloons. 17. Why a liquid cannot be poured from a teapot having an air-tight lid. 18. Why a gurgling sound is caused by pouring a liquid from a bottle. 19. Why the fall of the mercury in the barometer indicates a coming storm. 20. Why the height of the column of mercury in the barometer is less in foggy or misty weather than when the air is clear. 21. Why bubbles rise to the surface when we put a lump of sugar into a cup of tea or coffee. 22. Why the stream is continuous in a suction and force-pump.

PROBLEMS FOR EXERCISE.

1. What is the weight of $2\frac{1}{2}$ cubic feet of air?

2. A vessel full of air weighs 986 grains; but when exhausted, it weighs 930 grains. What is its capacity in cubic inches?

3. If, under the pressure of one atmosphere, a certain quantity of oxygen gas occupies 27 cubic inches, what space would it occupy under a pressure of $2\frac{1}{4}$ atmospheres?

4. What is the total pressure on the piston of a steam-engine 30 inches in diameter, when the force of steam is equal to $3\frac{1}{2}$ atmospheres?

5. What is the total downward pressure of the atmosphere on the roof of a house 50 feet by 20 feet? What is the upward pressure?

6. When the mercury in the barometer stands at $29\frac{1}{4}$ inches, how high a column of water will the atmosphere support, the specific gravity of mercury being 13.6?

7. If, under the pressure of one atmosphere, a certain quantity of hydrogen gas occupies 50 cubic inches, under what pressure would it occupy 30 cubic inches?

8. If the pressure on a pair of Magdeburg hemispheres is equal to 1,620 pounds, how many square inches are contained in the surface of each, the vacuum being .916?

9. To what height could a liquid the specific gravity of which is 1.43 be raised by a common suction pump when the mercury stands in the barometer at $29\frac{1}{2}$ inches?

10. A rectangular air-tight box, 6 inches long, 4 inches wide, and 3 inches deep, was partly exhausted of air, the top being pressed in when the vacuum within it was .375. How much pressure did it withstand?

11. How many pounds pressure would there have been on the top and sides, if the vacuum had been .65?

12. In a theoretically perfect air-pump, what degree of rarefaction is produced by 12 strokes, the volume of the receiver being twice that of the barrel?

CHAPTER V.

ACOUSTICS.

I.—PRODUCTION, PROPAGATION, AND REFLECTION OF SOUND.

146. **Acoustics** is that branch of physics which treats of sound.

It is to be distinguished from *music*, which treats of a particular class of sounds, and their production and combination to express or excite pleasurable emotions; while *acoustics* explains the physical laws underlying all phenomena of this kind.

147. **Sound** is a peculiar sensation excited in the organ of hearing by the vibratory motion of bodies, the effects of which are transmitted to the ear through an elastic medium.

Sound is to be distinguished from the vibrations which produce it. Being a sensation, it could have no existence without that of an organized being to perceive it; though, of course, the vibrations might occur. Nor could it exist without an elastic medium to convey the vibrations to the sentient organism.

148. **Sound is caused** by the rapid vibrations which take place in the molecules of bodies, when they are disturbed by a shock or by friction.

These molecules thus agitated tend to regain their normal state of equilibrium, which they do not reach until after performing many vibrations, or movements to and fro, of constantly decreasing amplitude.

Vibrations of sounding bodies are easily made visible. If a light powder be sprinkled on a body which is emitting a musical sound, the particles of the powder will arrange themselves in particular forms. The vibrations of a stretched cord when producing sound can sometimes be seen.

149. **Sonorous bodies** are elastic bodies which are capable of emitting regular and continuous sounds. These sounds are usually called *musical sounds*.

Such sounds are distinguished from *noises*. The latter are either confused mixtures of many discordant sounds, or of very short duration, as the report of a cannon. All sounds may, however, be considered as having a musical value, more or less determinate.

150. **Sounds are propagated** by an elastic medium interposed between the ear and the sonorous body, with the latter of which it vibrates. This medium is usually the air; but all gases, vapors, liquids, and also solids, transmit sound, more or less readily.



Fig. 82.

The following experiment will illustrate this: Place a small metal bell, which is continually struck by a hammer moved by clockwork, as in alarm clocks, under the receiver of an air-pump (Fig. 82); and it will be found that as the air is exhausted, the sound gradually becomes inaudible. To prevent the sound from being transmitted through the plate, the bell-machine must be placed on wadding. If any vapor or gas is admitted into the exhausted receiver, the sound will be again heard, showing that this, like air, may be a medium for the propagation of sound.

151. Sound is propagated by liquids and solids with a much greater velocity than by air or any other elastic fluid.

When two bodies strike against each other, under water, the shock is heard with great distinctness. The diver in the depths of the water can hear the sound of voices at the surface. The scratching of a pin or the ticking of a watch at one end of a board is quite audible when the ear is placed close to the other end. Persons sometimes put their ear close to the railroad track to hear the sound of a distant train.

152. The **intensity of sound** is affected by (1) the distance of the sounding body, (2) the amplitude of the vibrations, (3) the density of the air where the sound is produced, (4) the direction of the currents of air, and (5) the neighborhood of other sounding bodies.

1. *The intensity of sound is inversely as the square of the distance of the sounding body from the ear.* That is, for double the distance the intensity of the sound is only one-fourth. The distance at which sounds can be heard depends on their intensity. The report of a volcano at St. Vincent was heard at Demerara, 300 miles away; and the sound of the cannon at Waterloo was heard at Dover.

2. *The intensity of sound increases with the amplitude of the vibrations of the sonorous body.* This may be seen to a certain extent by means of vibrating cords; for, if they are long, the oscillations are visible; and it is seen that the sound becomes less intense as the amplitude of the oscillations diminishes.

3. *The intensity of sound is affected by the density of the air.* This has already

been shown by means of the experiment with the bell under the receiver of the air-pump (Fig. 82). In hydrogen, which is about $\frac{1}{14}$ the density of air, sounds are much feebler; in carbonic acid, the density of which is 1.529, compared with air, sounds are more intense. On high mountains, where the air is rarefied, ordinary speaking is scarcely audible, and the discharge of a pistol produces a sound as feeble as that of a pop-gun. On the other hand, in water, the ticking of a watch is heard at the distance of 23 feet, while in air it can be heard only 10 feet.

4. *The intensity of sound is affected by the force and direction of the wind.* Thus, in calm weather, sound is propagated more readily than when there is wind. Of course sound is more intense in the direction of the wind than against it.

5. *Sound is rendered more intense by the proximity of a sonorous body.* A string that vibrates in free air emits but a feeble sound; but, when it vibrates above a sounding-box, as in the violin, guitar, etc., its sound is much more intense. This is due to the fact that the box and the air which it contains vibrate in unison with the string.



Fig. 83.

This principle is illustrated by the following experiment: A hemispherical brass vessel, A (Fig. 83), is set in vibration by means of a violin bow; near it there is a hollow card-board cylinder, B, closed at the farther end. By means of a handle this cylinder can be turned on its support, so as to be inclined at any given degree toward the vessel. The cylinder is fixed on a slide, C, by which it can be placed at any distance from it. When the vessel is made to vibrate, with the cylinder turned toward it, the strengthening of the sound is very remarkable; while, if the cylinder is turned away, the sound loses a great part of its intensity. The cylinder is made to vibrate in unison with the brass vessel by adjusting it to a certain depth, this being effected by making one part slide into the other.

153. Speaking-Tubes.—By the use of tubes the effect of distance in diminishing the intensity of sound may be to a geat extent counteracted. This is seen in the use of *speaking-tubes.*

In this case the sound-waves are confined, and thus transmitted with little alteration. In very large tubes, or where the sides are rough, the advantage is much diminished.

The *velocity of sound* in air, at a temperature of 62° F., is 1,125 feet in a

second, or about 51 miles in four minutes. In water the velocity is about four times as great; in iron, nearly fifteen times as great.

The fact that sound requires a certain amount of time to travel from one place to another is illustrated by numerous phenomena. For example, the sound of thunder is not heard till some time after the flash of lightning which caused it; and, if we look at a mason at a distance striking a stone, we shall see the blow before we hear the sound. The superior conductivity of solids can be illustrated by placing the ear against a rock in which, at a distance, blasting is being made, when two sounds will be heard separated by an interval, the one being the sound of the hammer transmitted by the rock, and the other the same sound conveyed more slowly by the air.

154. **The velocity of all kinds of sounds,** whether strong or weak, deep or acute, is the same, provided the temperature remain unchanged.

The experiments of Biot on the conductivity of sound in tubes proved that a tune played on a flute at one end of a tube 1,040 yards long, could be heard without alteration at the other end; and a tune played at a distance by a band in the open air is heard unaltered except in distinctness or intensity. This, obviously, would not be the case, if some sounds traveled faster than others.

The sound produced by a violent explosion or concussion seems, however, to travel more rapidly than one of less strength. In artillery practice it has been observed that persons a long distance from the gun heard the report before the officer's command reached the ear; and experiments in blasting rocks have shown that the heavier the charge of gunpowder, the more rapidly the report traveled.

If a medium through which sound travels consists of different substances, the communication is enfeebled. Thus soft earth conducts sound badly, while a hard compact mass conducts it well.

155. **Reflection of Sound.**—When the sound-waves are not obstructed, they pass onward in the form of concentric spheres; but when they meet with an obstacle, they return upon themselves, forming new concentric waves, seeming to proceed from another center on the opposite side of the obstacle. This gives rise to the reflection of sound.

This phenomenon is illustrated in Fig. 84, which represents a series of sound-waves striking against the surface P Q, from which they are reflected. For example, the incident wave M C D N, emitted from the center A, is reflected in the wave represented by the arc C K D of a circle, the center, *a*, of which is as far behind the obstructing surface as it is before it. If any point, as C, of the reflecting surface be joined to the center of reflection, and a perpendicular, C H, be drawn, the angle A C H is called the *angle of incidence*, and B C H, formed by the prolongation of *a* C, the *angle of reflection*. These two angles are always equal, and the incident and reflected rays are always in the same plane, perpendicular to

the reflecting surface. Thus the wave which moves in the direction A C is reflected in the direction C B, so that a person situated at B, hears not only the

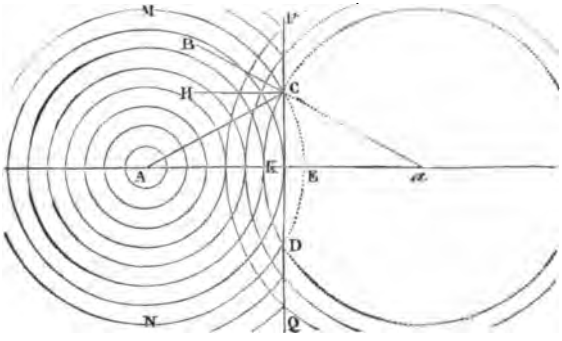


Fig. 84.

sound proceeding from A, but a second sound that appears to come from C. This causes *echoes*.

156. An **echo** is the repetition of a sound in the air, caused by its reflection from some obstructing surface.

The reflecting surface must be far enough for us to distinguish the echo from the sound itself. If the sound be sharp and quick, a distance of 55 feet is sufficient; but for articulate sounds, it must be at least 112½ feet. Because one can pronounce or hear five syllables in a second, or 225 feet for each syllable, 1,125 feet per second being the velocity of sound; and if the reflecting surface be 112½ feet distant, the sound in going and returning will travel just 225 feet. At that distance, only the last syllable of a word or sentence would be heard; at three times that distance, three syllables; and so on.

When the distance is too short for the reflected sound to be heard, it blends with the direct sound, which is strengthened thereby. This is called *resonance*. Thus the bare walls of a room increase resonance, while tapestry or hangings, being bad reflectors, deaden the sound.

157. **Multiple echoes** are several successive repetitions of the same sound by reflection from different surfaces.

There are echoes which repeat the same sound a large number of times. In the chateau of Simonetta, in Italy, an echo is repeated thirty times. In Fairfax County, Va., there is an echo which will return twenty notes played on a flute. Curved surfaces concentrate, or focalize the sound, as well as reflect it, all the different reflected waves being directed to a single point. In the *whispering gallery* of St. Paul's, London, the faintest sound made in one part of the dome may be heard at the opposite side, though inaudible at every intermediate point. In a circular building called the Colosseum, in London, Wheatstone, placing himself close to the upper wall, found a word to be repeated a great many times. A

single exclamation, *ha!* became a peal of laughter, *ha! ha! ha!* while the tearing of a piece of paper sounded like the patter of hail.

158. The **speaking-trumpet,** used to make the voice audible at a great distance, is an application of the reflection of sound.

It consists of a tube tapering outward, terminating in a short spreading tube at the end (called the *bell*), and supplied with a mouthpiece (Fig. 85). The



Fig. 85.

sound of the voice is thrown outward by reflection from the sides, and appears also to be strengthened by the vibrations in the tube. The *ear-trumpet* is merely an inverted speaking-trumpet, as it collects the waves of sound and reflects them into the ear.

159. The **stethoscope** is an instrument used to hear the beating of the heart, or the sounds of respiration of the lungs.

An improved form of this instrument is represented in Fig. 87. Two sheets of india-rubber, *c* and *a* (Fig. 86), are fixed to the circular edge of a hollow metal

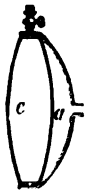


Fig. 86.



Fig. 87.

hemisphere. The edge is provided with a stop-cock, that the sheets may be inflated, so as to present the appearance of a double convex lens, as shown in Fig. 87. To the hemisphere is fixed an india-rubber tube, terminated with an ivory ear-piece. When the membrane is applied to the chest, the sounds of the lungs or heart are transmitted to the air in the chamber *c a*, and thence by the tube to the ear. This process is called *auscultation*.

II.—MEASUREMENT OF THE NUMBER OF VIBRATIONS.

160. Various instruments have been devised to measure the number of vibrations in a second required to produce a particular sound, such as a musical note of a certain pitch.

That invented by the French physicist Savart consists of a toothed wheel, made to revolve with great rapidity, against which a card is held, until it is set vibrating, and thus made to emit the tone specified, when an indicator shows the number of revolutions of the wheel, and this number multiplied by the number of teeth in the wheel gives the number of vibrations of the card during the time.

The *sirene* (Fig. 88) is an apparatus devised for the same purpose. The lower part consists of a cylindrical box, O, closed by a fixed plate, B, on which rests a vertical rod, T (Fig. 90), having attached to it a disc, A, moving with the rod. In this disc there are equidistant circular holes, and the same in the plate B, corresponding to them in position, but inclined in opposite directions, as shown at *m* and *n* (Fig. 89). The machine being placed on the table of a bellows, and a continuous current of air sent through the cylinder O, when the current passes

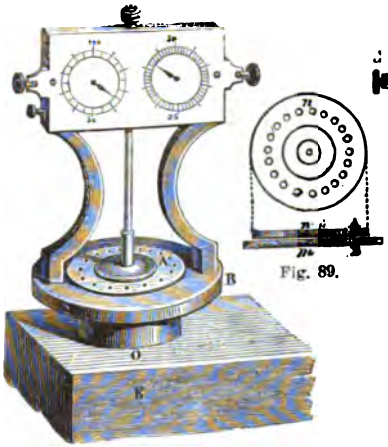


Fig. 88.

Fig. 89.

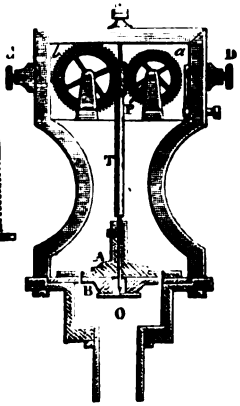


Fig. 90.

through *m* it strikes obliquely against the sides of the hole *n* and gives a rotatory motion to the disc. If, for example, there are eighteen holes in the movable disc, in every revolution these eighteen holes and those of the plate B will come opposite to each other eighteen times, allowing the air to pass through. Thus each revolution will cause eighteen vibrations of the air; and, when the rotatory motion is sufficiently rapid, a musical note is produced, high or low, according to the number of vibrations, which can easily be ascertained for a given time, say, a second, by knowing the number of revolutions of the disc. For this purpose an endless screw on the rod T (Fig. 90) transmits the motion to a wheel, *a*, having one hundred teeth, moving thus one tooth at every revolution of the disc; while, at every complete revolution of this wheel, the catch P moves the wheel *b* one tooth. A hand fixed at the axis of each of these wheels moves round a dial, as shown in Fig. 88, one giving the number of turns of the disc, the other

the hundreds of turns. The screws D and C uncouple the wheel *a* from the endless screw. When the desired note is produced, the number of vibrations is read off from the dials.

With the same velocity, the sirene gives the same note in other gases as in air, and also in water, showing that the quality of the sound depends on the number of vibrations, and not on the nature of the medium of transmission. This instrument received its name *sirene*, because it emits sounds under water.*

161. **A bellows,** in acoustics, is an apparatus by which wind instruments, such as the sirene and organ, are worked.

Between the legs of a table, the pair of bellows S (Fig. 91) is worked by

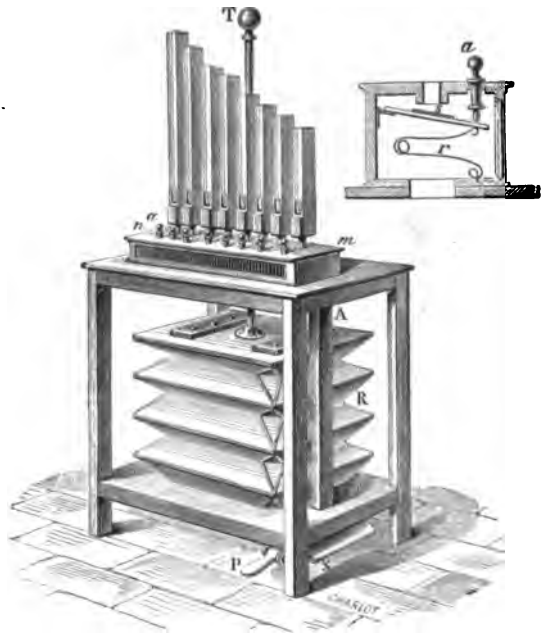


Fig. 91.

the pedal P; R is a reservoir formed by flexible leather, containing air, which, by means of pressure on the reservoir, communicated by the rod T, is forced through a pipe into a chest, *m n*, fixed on the table. In this chest there are small holes, each closed by a leather valve, *s*, which is held by a spring, *r*, and is opened by pressing on a pin, *a*, in front of the box.

* It was named after the mythical *sirens*, damsels dwelling in the Mediterranean Sea, near the island of Caprea, who were said to fascinate all who approached them by their delightful music.

162. The **graphic method** of determining the number of vibrations proper to a particular sound consists in fixing a fine point to the body emitting the sound, and causing it to trace the vibrations on a prepared surface.

Such a machine, called a *vibroscope*, is shown in Fig. 92. Round the cylinder A, turned by means of a handle, the lower part of the axis being a screw work-

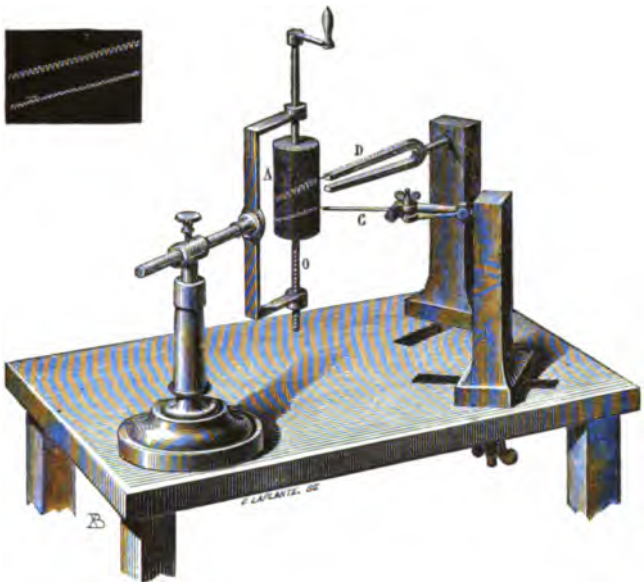


Fig. 92.

ing in a nut, is rolled a sheet of paper covered with lampblack. To the tuning-fork D, or the steel rod G, is fixed a fine point, so as to graze very lightly the surface of the cylinder. When either of these is set in vibration, and the cylinder turned so as to cause it to move up or down, a line is traced which shows by its undulations the vibrations made. (See the adjoining cut, showing the sheet of paper unwound from the cylinder.)

III.—PHYSICAL THEORY OF MUSIC.

163. **Musical sounds** result from continuous and uniform vibrations, above a certain degree of rapidity, which is necessary in order that they may be perceived by the ear. Musical sounds have three leading qualities: *pitch*, *intensity*, and *character*.

Uniformity and rapidity are the essential qualities of vibrations that produce musical sounds. If a watch could be caused to tick with sufficient rapidity, the ticks would blend, and produce a musical sound. If, says Tyndall, the puffs of a locomotive could be so increased as to number fifty or sixty a second, the approach of the engine would be heralded by an organ peal of tremendous power.

Pitch depends on the rapidity of the vibrations; *intensity*, on the extent, or amplitude, of the vibrations; *character*, on the substance or instrument producing them. The greater the number of vibrations in a second, the higher the pitch.

Character is called *timbre* by the French, and *color* by the Germans. The character of a note, C for example, is very different when produced by the human voice, a piano, or a violin; yet it may be precisely the same note. When sounds produce the same note, however different the character of the tone may be, the effect is called *unison*.

164. **Musical sounds are produced** by the vibrations of strings, and by columns of air in wind instruments, reeds, etc.

165. The **vibrations of strings,** which are commonly of catgut, as those of the violin, or steel wire, as in the piano, are *transverse* or *longitudinal*; but the former are alone important. They are produced by drawing a bow across the string, by striking it, or by jerking it sharply, as in the guitar and harp. A single stretched string is called a *monochord*.

166. The **sonometer,** or **monochord,** is an apparatus for studying the transverse vibrations of strings.

This instrument is represented in Fig. 93. The string is stretched over two

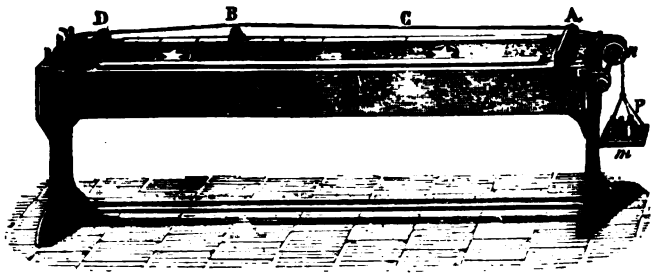


Fig. 93.

bridges, A and D, by means of a pulley, *n*, over which it passes, sustaining the weight P, which can be increased at pleasure. The bridges rest on a sounding-box; and by means of a movable bridge, B, the length of the string to be vibrated can be altered. By means of this instrument, the following laws have been established:

1. The tension remaining the same, the number of vibrations in a second is inversely as the length.

2. The number of vibrations in a second is inversely as the diameter of the string.

3. The number of vibrations in a second is directly as the square root of the tension, or stretching weight.

4. The number of vibrations in a second is inversely as the square root of the density of the string.

If we place the bridge B (Fig. 93) at the middle of the string, we shall find that one-half of it will have twice the number of vibrations in the same time; and the note produced will be an *octave* above that produced by the whole string, called its *fundamental note*. The lengths for other notes are ascertained in a similar manner.

167. The **musical scale** contains seven notes designated by the first seven letters of the alphabet, from A to G, inclusive. These notes are produced by the vibrations proper to the following relative lengths of the string, taking C as the fundamental note:

C,	D,	E,	F,	G,	A,	B,	*c*,
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

The notes C and *c* so closely resemble each other that they are thus called by the same name. The interval between C and *c* is called an *octave* because *c* is the *eighth* note above the fundamental, and is the first note in the second octave. C is an octave below *c*; and, conversely, *c* is an octave above C.

As by the first law the number of vibrations is inversely as the length, the following will indicate the proportion of vibrations for each note:

C,	D,	E,	F,	G,	A,	B,	*c*,
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

Or, reducing to whole numbers by multiplying each by 24:

24, 27, 30, 32, 36, 40, 45, 48.

Hence the intervals may be represented by the following fractions, each expressing the ratio of the note to the one preceding it:

C to D,	D to E,	E to F,	F to G,	G to A,	A to B,	B to C,
$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

We thus see that the intervals between C and D, F and G, and A and B are the same; as also between D and E and G and A, and between E and F and B and C. The intervals between the third and fourth and between the seventh and eighth are much shorter than the others. These are called *semi-tones*, or *minor tones;* while the others are *tones*, or *major tones*. The tones, as will be seen, differ by an interval, indistinguishable except by a highly cultivated ear. This interval is sometimes called a *comma*. The above represents what is called a *diatonic major scale.**

* "Pythagoras, who was the first to attempt the numerical evaluation of musical intervals, laid down a scheme of values slightly different from that which is now

The *wave length of a given note* may be deduced from the number of vibrations. Since sound travels at the rate of 1,120 feet a second, the wave length will be 1,120 feet divided by the number of vibrations in a second. Thus, if the number of vibrations per second be 560, the wave length will be 1120÷560=2 feet. While according to Helmholtz, the notes distinguishable by the ear range between 16 and 38,000 vibrations, or eleven octaves; those which are musically available range from about 40 to 4,000 vibrations, or within seven octaves.

168. **Nodes** are certain stationary points at aliquot divisions of a string, between which the parts tend to vibrate.

Let us suppose the string A D (Fig. 94) to begin vibrating; and while in

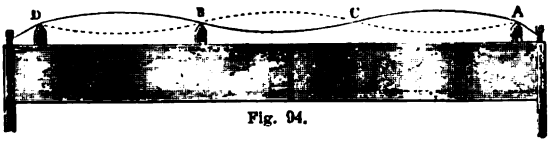


Fig. 94.



Fig. 95.

vibration let a point, B, be brought to rest by a stop, D B being one-third of A D; the result will be that not only will D B vibrate independently, but A B will divide itself in halves, each part vibrating separately. If D B were one-fourth of A D (Fig. 95), the remaining portion would vibrate in three separate parts: the whole string vibrating in fourths. The points B, C, C' are called *nodes;* and the parts of the string between them, *loops*. A vibrating string being *touched* lightly at any one of its nodes, is thrown into vibrations proper to each loop. Thus, conceive a vibrating string to be divided into seven equal parts; then, if the string be touched at any one of the points of division, the note produced will be the same as that emitted by a vibrating string one-seventh of the length. Such notes are called *harmonics*.

generally adopted. According to him, the intervals between the successive notes of the major scale are as follows:

C to D	E to F	G to A	B to C
$\frac{9}{8}$ $\frac{10}{9}$	$\frac{256}{243}$	$\frac{9}{8}$ $\frac{9}{8}$	$\frac{9}{8}$ $\frac{256}{243}$

In the ordinary system, the prime numbers which enter into the ratios are 2, 3, and 5; in the Pythagorean system they are only 2 and 3 [as $9=3^2$; $8=2^3$; $256=2^8$; and $243=3^5$]. Hence the intervals between any two notes of the Pythagorean scale can be expressed as the sum or difference of a certain number of octaves and fifths. In tuning a violin by making the intervals between the strings two fifths, the Pythagorean scheme is virtually employed."—*Deschanel.*

The same laws are applicable to wind instruments, the only difference being that the vibrations occur in a column of air within the instrument instead of a string. The column of air is shortened or lengthened by the stops, and similar nodes and loops exist as in vibrating strings.

169. **Reed Instruments** are those in which a simple elastic tongue is used to set the air in vibration, the tongue, or reed, being moved by a current of air.

The mouthpieces of the oboe, the bassoon, and the clarionet are applications of the reed, which are seen in its simplest form in the Jews' harp. Some organ pipes are reed pipes, others are mouth pipes.

The model of a reed pipe is represented in Fig. 96. It is fixed on the wind-chest Q of a bellows; and the vibrations of the reed can be seen through a piece of glass, E, fitting into the side. H is a wooden horn, which serves to strengthen the sound. Fig. 97 shows the reed out of the pipe.



Fig. 96.

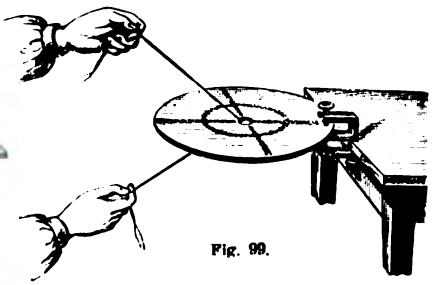


Fig. 97.

IV.—ANALYSIS AND REPRESENTATION OF VIBRATIONS.

170. **Vibrations of Plates.**—The nodal points and lines of vibrating plates may be exhibited to the eye by covering the plates with fine sand and setting them into vibration.


Fig. 98.


Fig. 99.

Fix a plate in the center, as in Fig. 98, and having covered it with fine sand, draw a bow rapidly across one of the edges; or fix it at some other point, and cause it to vibrate by rapidly drawing a string covered with resin against the edge of a hole in the center (Fig. 99). As soon as the vibrations commence, the sand leaves the vibrating parts, and collects at the nodal lines and points Their position may be determined by touching the vibrating plates at the points where it is desired they should be shown. The figures thus formed are sometimes called *acoustic figures.*

171. The **number of vibrations** in plates of the same kind and shape, and giving the same system of nodal lines, is directly as the thickness of the plates, and inversely as their area.

Gongs and cymbals are examples of instruments in which sounds are produced by the vibrations of metal plates.

172. The **vibrations of membranes** stretched, as in the drum, cause a sound which is acute in inverse proportion to the area, and directly as the tension with which they are stretched.

In Fig. 100, the membrane is represented as set in vibration by the vibration

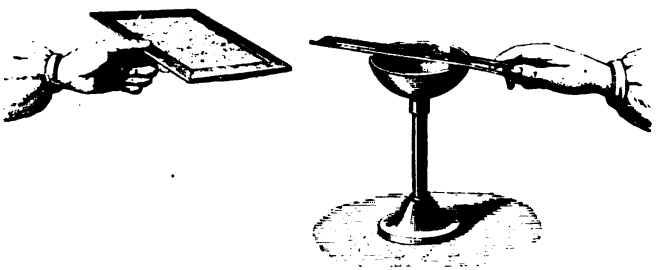


Fig. 100.

of the air caused by a sounding-bell near it. Fine sand strewn upon it shows the nodal lines, as upon the plates. Membranes are easily influenced by the vibrations of the air, on account of their small mass, large surface, and readiness to subdivide. With a pretty strong whistle, nodal lines may be produced in a membrane stretched on a frame, at the distant end of a large room.

173. **Interference of Sound.**—If two waves of sound of the same length proceed in the same direction, and if the undulations coincide, they strengthen one another; but, if they differ by half a wave length, they neutralize one another, and the result is silence. This is called the *interference of sound.*

174. **Visual Representation of Sounds.**—The vibratory motion of bodies may be exhibited to the eye, either directly or on a screen by means of the ingenious apparatus here described.

To one of the prongs of a tuning-fork a small mirror, m (Fig. 101), is attached, and to the other a counterpoise, n, which is required to make the tuning-fork vibrate regularly for a sufficient time. At a few yards' distance from the mirror, there is a lamp surrounded by a dark chimney, in which is a small hole, giving a single luminous point. The tuning-fork being at rest, the eye is placed so that the luminous point is seen in the direction of o. When the tuning-fork is made to vibrate, the image elongates so as to form a persistent image, $o\,i$, which diminishes as the amplitude of the vibration decreases. If, during the vibration of the mirror, the tuning-fork is rotated, a sinuous line, $o\,i\,x$, is produced.

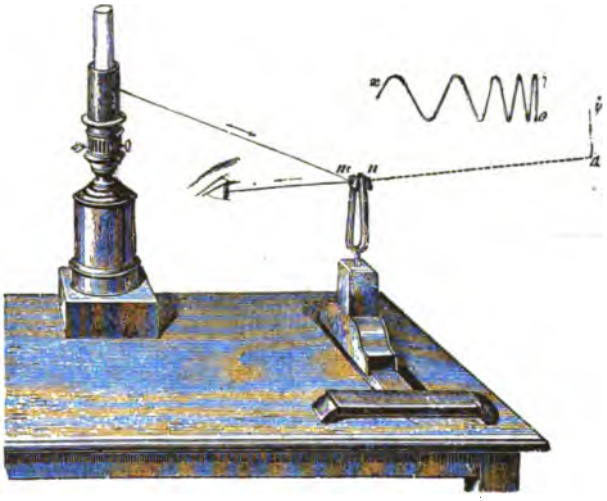


Fig. 101.

If, instead of viewing these effects directly, they are projected on the screen, the experiment is arranged as shown in Fig. 102. The pencil reflected from the vibrating mirror is reflected a second time from a fixed mirror, m, which sends it toward a lens, l, placed so as to project the images on the screen. By different applications of this method, various combinations of two vibratory motions may be optically presented on the screen.

175. The **phonautograph** is an instrument used to register the vibrations of solid bodies, of wind instruments, of the human voice in singing, and even those made by the report of firearms, or of thunder. It was invented by Léon Scott, a French physicist.

This apparatus, represented in Fig. 103, consists of an ellipsoidal band AB, made of plaster-of-Paris, about 18 inches long, and a foot in diameter at its thickest part. The end A is open, but the end B is closed by a solid bottom, to the middle of which is fixed a brass tube, a, bent at an elbow, and terminated by a

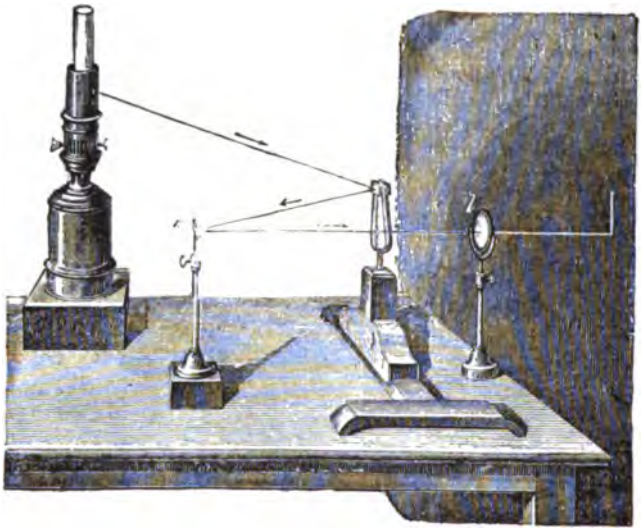


Fig. 102.

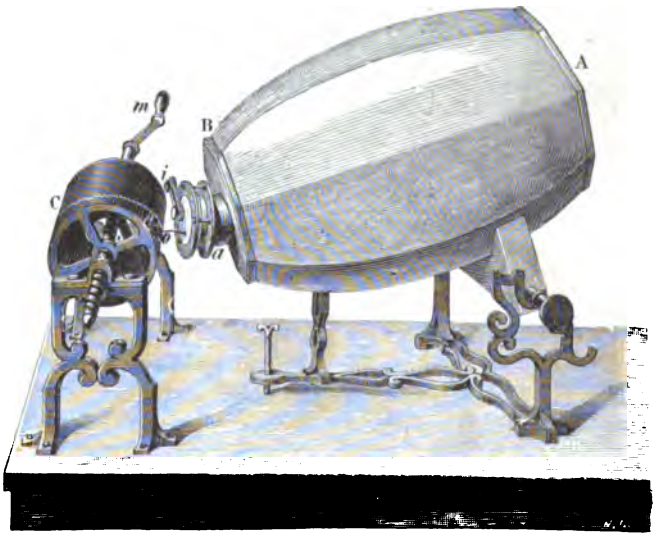


Fig. 103.

ring on which is fixed a flexible membrane, that may be stretched to any required degree by means of a second ring. Near the center of the membrane, fixed by sealing-wax, is a hog's bristle, which acts as a style, and moves with the membrane. When a sound is produced near the apparatus, vibrations in unison with it are produced in the air in the elipsoid, the membrane, and the style; and these are recorded on the paper wound around the cylinder C, as in the vibroscope (Fig. 92). In Fig. 104 is seen the trace when a simple note is sung, strengthened by means of its upper octave, the latter note being represented by the curve of smaller amplitude. Fig. 105 represents the sound produced jointly by two



Fig. 104.



Fig. 105.



Fig. 106.



Fig. 107.

pipes, the notes of which differ by an octave. In Fig. 106 are represented the vibrations of a tuning-fork, below which are shown the rolling sound of the letter R; and in Fig. 107 are shown the contrast between the regular vibrations of a tuning-fork and those of a tin plate when struck with the finger.

176. **Effect of Sound on Flames.**—A gas flame burning in a tube emits a musical sound, the character of which is determined by the size of the jet and the length of the tube. Such flames are called *singing flames*, and are, under certain conditions, very sensitive to external sounds.

The following interesting description of an experiment by Prof. Tyndall will illustrate this: "I place a tube, 12 inches long, over a flame occupying a position within the tube about an inch and a half from its lower end. When the proper note is sounded, the flame trembles but does not sing. I lower the tube,

so that the flame may be three inches from its lower end; it bursts spontaneously into song. Now, between these two positions there is a third, at which, if the flame be placed, it will burn silently; but, if it be excited by the voice, it will sing and continue to sing. In this position, then, it is able to sing, but it requires a start. It is, as it were, on the brink of a precipice, but it requires to be pushed over."

177. **Sensitive flames** are flames that, though not surrounded by resonant tubes, are sensitive to sound, and by their action and form indicate the nature of sounds in their vicinity, or sometimes at a considerable distance.

Flames emitted from particular burners, and therefore of a special character as to height and size, manifest in a wonderful degree this sympathy with sounds.

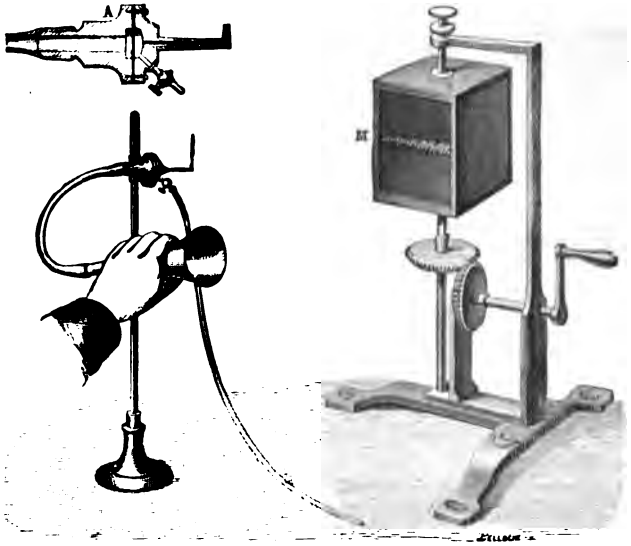


Fig. 108.

Prof. Tyndall, in speaking of a flame 24 inches high, issuing from a steatite, or soap-stone, burner, thus describes its sensitiveness: "The slightest tap on a distant anvil reduces its height to seven inches. When I shake this bunch of keys, the flame is violently agitated, and emits a loud roar. I cannot walk across the floor without agitating it. The crumpling or tearing of a bit of paper, or the rustle of a silk dress, does the same. It is startled by the patter of a rain-drop. At every tick of the watch it falls; and the winding up of the watch produces tumult. From a distance of 30 yards, I have chirruped to this flame and caused it to fall and roar."

By an apparatus invented by Koenig, the pulsations of gas flames under the influence of the sonorous waves are optically presented on a revolving mirror. This is shown in Fig. 108. A metal capsule, a section of which is represented at A, is divided into two compartments by a thin membrane of India rubber;

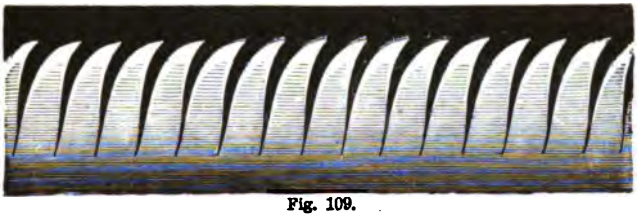


Fig. 109.



Fig. 110.



Fig. 111.



Fig. 112.

on the right of this figure is a gas-jet, below it the tube conveying the gas; on the left is a tube terminating in a mouthpiece, into which any note may be sung, or proceed from any instrument. When the sound-waves enter the capsule, they are transmitted by means of the membrane to the air within, and affect the flame, causing alternations that are rendered distinct by being received

on a mirror, M, with four faces, which may be turned by two cog-wheels and a handle. As long as the flame burns steadily, there appears in the mirror, as it is turned, a continuous band of light; but if the capsule is connected with a sounding tube yielding the fundamental note, the image of the flame takes the form shown in Fig. 109; and when the sound is changed to the octave, the flame appears as in Fig. 110. If the two sounds reach the capsule simultaneously, the flame assumes the appearance shown in Fig. 111; and if one of the sounds is the fundamental note, and the other the third above, the flame assumes the form seen in Fig. 112. The analysis of vocal sounds has been accomplished by this means.

178. The phonograph is an instrument, invented by Edison, for registering and reproducing sounds.

The construction of this ingenious apparatus is quite simple. The mouth-

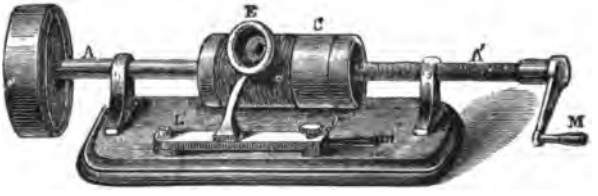


Fig. 113.

piece E (Fig. 113) is closed by a thin, elastic metal disc. By means of a spring, a small steel point, rounded at the end, is fixed at the back of the disc, and by gently pressing against the surface of tin-foil transfers to it the vibrations of the disc through small pieces of India rubber tubing; while another small piece of tubing helps to deaden the vibrations of the spring itself. This arrangement is shown on a larger scale in Fig. 114.

The tin-foil is placed on a long cylinder, C, having on its surface a very accurately constructed spiral groove, the threads being about one-tenth of an inch apart. The cylinder works on a screw, A A', the thread of which is the same as that of the cylinder, and is turned by a handle, M, the motion being regulated by a fly-wheel at A. The position of the mouthpiece is adjusted by the arrangement L *r m*.

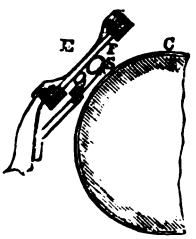


Fig. 114.

When the cylinder is turned with a uniform motion, the vibrations of the disc, caused by speaking or singing through the mouthpiece, produce a series of dots upon the tin-foil, which retains them; so that, when the part which the mouthpiece plays is reversed, the indented tin-foil reproduces the sound. To effect this a special mouthpiece of greater size is used, which is so adjusted that the point works along the indentations in the groove, sets the disc in vibration, and reproduces the sounds. In order to produce perfect uniformity in the rotation of the cylinder, clockwork may be used. The

character of the marks on the tin-foil, as to their length, depth, and position, exactly represents the quality of the sounds; and thus are recorded all the tones and modulations of the voice in speaking or singing. According to Edison, as many as 40,000 words can be registered on a space not exceeding 10 square inches. The sheets of tin-foil containing the indentations can be taken from the cylinder, and kept for use when wanted.

V.—THE HUMAN VOICE AND EAR.

179. The **organ of vocal sounds** is the larynx, situated at the upper end of the trachea, or windpipe.

A horizontal section of this organ is represented in Fig. 115. It is formed by cartilages, *b b*, connected by muscles, by means of which a great variety of motions may be effected. These muscles are connected with two elastic membranes, or bands, with broad bases fixed to the larynx, and sharp edges, *c c*, called the *vocal chords*. By means of the muscles, these chords are more or less stretched, and the space between them—the *vocal slit*—is contracted or widened. Ordinarily the air passes through *o*; but in singing this is closed, and the vocal chords being stretched, are put in vibration by the air, and different notes produced.

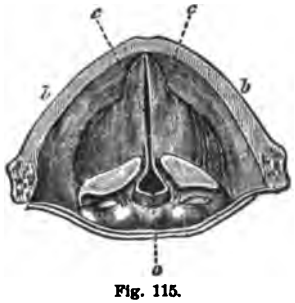


Fig. 115.

The longer the larynx, and the larger and thicker the vocal chords, the deeper the voice. On this account the male voice differs from the female. The ordinary compass of the human voice is within two octaves; but some voices greatly exceed that range. The Italian vocalist Catalani is said to have had a voice of three and a half octaves. The sound of the human voice is very rich in its variety of tones as well as in harmonics.*

180. **Perception of Sounds.**—The *ear*, the organ of hearing, is a very delicate and complex structure. It consists of several parts, the arrangement and office of which will be understood from the following description.

The *external ear* collects and transmits the sound through the auditory passage, *a* (Fig. 116), to the drum, or *tympanum*, *t*, which is a delicate and tightly stretched membrane in front of the tympanic cavity, containing several small

* "The average compass of the human voice is about two octaves. The deep F of a bass-singer has 87, and the upper G of the treble 775 vibrations per second. Voices which exceed either of these limits are regarded as deep or high, though a few voices exceed them to the extent of nearly an octave."—*Deschanel.*

bones, which conduct the motion to the inner ear, or *labyrinth*. One, the *hammer*, *d*, is attached at one end to the drum, and at the other jointed to the *anvil*, *e*; and the latter is connected by the *stirrup-bone*, *f*, to the *oval window*, an aperture closed by a fine membrane, separating the tympanic cavity from the labyrinth. The latter is filled with fluid, and consists of three parts—the *vestibule*, closed by the oval window, the three semicircular canals *k*, *k*, *k*, and the spiral-shaped *cochlea*, *s*, which transmits the vibrations to the auditory nerve *n*, which is divided into a vast number of fine filaments (*Corti's fibers*), each of which seems to be tuned for a particular note, so that when the vibrations of that note are transmitted by means of the stirrup-bone and the fluid of the labyrinth, only those filaments vibrate that are in unison with that note. This wonderful piece of mechanism is like a lute of 3,000 strings, which is the number of the filaments. The tympanic cavity is also connected with the cavity of the mouth by the Eustachian tube *b*; so that the air in it may be always under the same pressure. By either condensing or rarefying the air behind the tympanum, we produce deafness to sounds of low pitch.



Fig. 116.

The capacity to perceive sounds varies in different persons; but the ordinary range of the ear is about eleven octaves. Most ears are more sensitive to the higher notes than the lower ones; but, on the contrary, Prof. Tyndall says: "The squeak of the bat, the sound of the cricket, even the chirp of the common house-sparrow, are unheard by some people, who for lower sounds possess a sensitive ear." The ear is far more sensitive to vibrations of sound than the eye to those of light; for the quickest vibrations discernible by the eye have only about twice the rapidity of the slowest; while, in the case of the ear, the quickest vibrations have more than two thousand times the rapidity of the slowest. The ear has a range of about eleven octaves, according to Tyndall, while the eye has but little more than one.*

* "The human ear is limited in its range of hearing musical sounds. If the vibrations number less than 16 a second, we are conscious only of separate shocks. If they exceed 38,000 a second, the consciousness of sound ceases altogether. The range of the best ear covers about eleven octaves, but an auditory range limited to six or seven octaves is not uncommon."—*Tyndall.*

SYNOPSIS FOR REVIEW.

ACOUSTICS.

I.—PRODUCTION, PROPAGATION, AND REFLECTION OF SOUND.

1. *Definitions:* 1. Acoustics. 2. Sound.
2. *Cause of Sound.*—Sonorous bodies.
3. *Mediums of Propagation.*
4. *Intensity of Sound, as related to:*
 1. Distance.
 2. Amplitude of vibrations.
 3. Density of the air.
 4. Force and direction of the wind.
 5. Proximity of a sonorous body.
5. *Speaking-Tubes.*
6. *Velocity of Sound:* 1. In air. 2. In liquids. 3. In solids.
7. *Reflection of Sound:*
 1. How illustrated.
 2. Echoes: 1. Simple. 2. Multiple.
 3. Resonance.
 4. Speaking and ear-trumpets.
8. *Stethoscope:*
 1. Construction.
 2. Use.

II.—MEASUREMENT OF THE NUMBER OF VIBRATIONS.

1. *Apparatus for:* 1. Savart's apparatus. 2. Sirene.
2. *Graphic Method.* (Vibroscope.)

III.—PHYSICAL THEORY OF MUSIC.

1. *Musical Sounds:* 1. Cause. 2. Leading qualities.
2. *Vibrations of Strings:* 1. Transverse. 2. Longitudinal.
3. *Sonometer*, or *Monochord.*
 1. Construction and use.
 2. Laws established by.
4. *Musical Scale.*
 1. Notes, their relation to:
 1. Length of string.
 2. Number of vibrations.
 3. Wave length.
 2. Intervals in the diatonic scale.
5. *Nodes and Loops.*—Harmonics.
6. *Reed Instruments.*
 Reeds:
 1. Construction.
 2. Use.

IV.—ANALYSIS AND REPRESENTATION OF VIBRATIONS.

1. *Vibration of Plates:*
 1. Nodal points and lines.
 2. Law as to vibrations.
2. *Vibration of Membranes.*
3. *Interference of Sound.*
4. *Visual Representation of Sound.* (Phonautograph.)
5. *Effect of Sound on Flames:*
 1. Singing flames.
 2. Sensitive flames.
 3. Koenig's apparatus.
6. *Phonograph.*

V.—HUMAN VOICE AND EAR.

1. *Larynx and Vocal Chords.*
2. *Perception of Sounds.*
 1. Structure of ear.
 2. Delicacy of ear.

APPLICATION OF PRINCIPLES.

Explain the following: 1. Why a tremulous movement is felt in the floor of an apartment near a piano-forte when it is played. 2. Why no sound is heard when a bell is rung under the receiver of an air-pump. 3. Why an approaching train of cars can be heard at a long distance by applying the ear to the railroad track. 4. Why no sound is emitted by soft, inelastic bodies when they are struck. 5. Why music sounds better in unfurnished than in furnished rooms. 6. Why the voice is feeble on the top of a mountain. 7. Why sounds are peculiarly clear on a frosty morning. 8. Why a speaker finds more difficulty in making himself heard in a crowded auditorium. 9. Why, when a man is seen at a distance blasting rock, the sound is separated from the blow by an interval of time. 10. Why a person is enabled to hear better by using an ear-trumpet. 11. Why the ticking of a watch can be heard at the end of a long plank by applying the ear to the other end. 12. Why there is no echo in a room of ordinary size. 13. Why the piano-tuner tightens the strings to tune the instrument. 14. Why a flute emits a lower note when all the stops are closed. 15. Why powder sprinkled on a body while emitting a musical sound arranges itself in a regular form. 16. Why sounds are more intense in an unpure than a pure atmosphere. 17. Why a short string produces a higher note than a long one. 18. Why, when music is played at a distance, the melody is unimpaired. 19. Why the discharge of a cannon sometimes reaches the ear before the word of command of the officer. 20. Why echoes are sometimes repeated.

PROBLEMS FOR EXERCISE.

1. A clap of thunder was heard 5 seconds after the flash of lightning was seen. What was the distance of the thunder-cloud?

2. At what distance is an observer from an object from which an echo is repeated 3 seconds after the sound is made?

3. How much greater is the intensity of sound at 10 feet than at 100 feet?

4. A stone is dropped into a well, and is heard to strike the water 10 seconds afterward. Required the depth of the well, considering the velocity of the sound 1,120 feet?

5. A meteor was seen to explode, and the sound reached the ear 2½ minutes afterward. What was its distance from the earth, calculating the average velocity of the sound at 1,000 feet?

6. How long would sound require to travel half a mile under water?

7. A wheel having 84 teeth in its circumference makes ten rotations a second, striking against an elastic strip, and emitting a musical note. How many vibrations a second are required to produce the note?

8. If a string producing a certain note vibrates 100 times a second, how many vibrations a second must it make to produce the octave?

9. If a musical note be produced by 216 vibrations in a second, what will be the vibrations corresponding to its third, its fifth, and the octave above, respectively?

10. If, in producing a certain note, a string makes 110 vibrations in a second, what is the length of the sound-waves?

CHAPTER VI.

HEAT.

I.—NATURE AND GENERAL EFFECTS OF HEAT.

181. **Heat** is a term used not only to express a particular sensation, but to denote the condition of matter which causes it. That which is called heat acts variously on bodies: it melts ice, boils water, makes metals red-hot, produces electrical currents, and decomposes compound bodies. That part of physics which treats of heat is usually called *Pyronomics.*

There are two theories advanced to account for the phenomena of heat: the *theory of emission* and the *theory of undulation*, or the *mechanical theory*. The first conceives heat to be caused by a subtle, imponderable fluid, surrounding the molecules of bodies, and passing from one body to another; the second supposes it to be due to the rapid vibrations of the molecules, or, in the words of Tyndall, that it is a "mode of motion." According to the latter theory, now generally received, heat is not a fluid, or substance, but a *condition of matter*. This condition can be transferred; for, when a heated body is placed in contact with a cooler one, the former imparts more molecular motion than it receives.

It is likewise assumed that there is an imponderable elastic ether pervading all matter and space. A heated body causes in this ether rapid vibrations, which being communicated to bodies increase their temperature, in a manner analogous to that by which sound is produced.

182. The **mechanical theory** of heat may be illustrated by various familiar phenomena, showing that, invariably, when heat is produced by motion, mechanical force is consumed.

Thus in rubbing two bodies against each other, motion is apparently destroyed by the friction; but, in fact, it is not, since it reappears in the form of heat, or molecular motion; and, if a body falls from a height, it seems to lose its momentum when it strikes against the ground; but this momentum (sometimes called *vis viva*) is only transformed to the particles, and still exists in the form of heat.*

* Some of the old writers conceived this connection between heat and motion. Thus Bacon, in his great work, the *Novum Organum*, said: "The form or true defini-

Count Rumford constructed a hollow cylinder of iron, and fitted into it a solid plunger, pressing firmly against the bottom. The cylinder was placed in a vessel containing water, and the plunger being turned by horse-power, the temperature of the water was raised from 60° to 107° in an hour; and, at the end of two hours and twenty minutes, the water was made to boil.

183. **General Effects of Heat.**—Heat raises the temperature of a body by increasing the *vis viva* of the particles; it expands the body by augmenting the amplitude of the oscillations of the particles, or wholly changes its state by altering the relative positions of the molecules. These effects constitute the *internal work*. But bodies being surrounded by atmospheric air, its pressure has to be overcome by the heat; and this constitutes its *external work*.

184. **Expansion.**—All bodies expand by the action of heat; gases, in general, being the most expansible, and liquids the least.

The expansion of solids may be considered in regard to one, two, or three dimensions, that is, as *linear*, *superficial*, or *cubical expansion*. To show the linear expansion of solids, the apparatus represented below (Fig. 117) may be used.

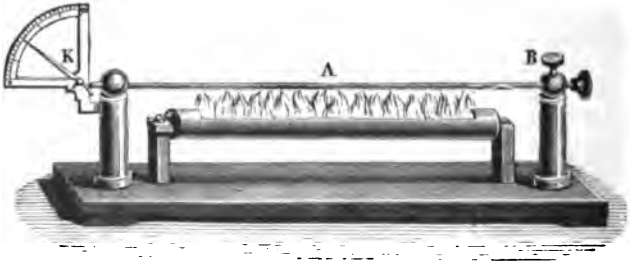


Fig. 117.

A metal rod, A, is fixed at one end by a screw, B, while the other end presses against the short arm of an index, K, which moves on a scale. Below the rod

tion of heat is, in a few words, as follows: Heat is a motion, expansive, restrained, and acting in its strife upon the smaller particles of the bodies. But the expansion is thus modified: while it expands all ways, it has at the same time an inclination upwards. And the struggle in the particles is modified also; it is not sluggish, but hurried and with violence." Locke said: "Heat is a very brisk agitation of the insensible parts of the object, which produces in us that emotion from which we denominate the object *hot;* so that what in our sensation is heat, in the object is nothing but motion." Rumford and Davy, in later times expressed similar views; but it was not until Mayer, in 1842, demonstrated the "mechanical equivalent of heat," showing the connection between heat and work, that modern physicists began earnestly to adopt this theory. The experiments of Mayer and Joule have greatly contributed to establish it; and the lectures of Tyndall, in 1862, served to illustrate and popularize it.

there is a sort of cylindrical lamp in which alcohol is burned. The needle K is at first at the zero point, but as the rod becomes heated, it expands, and moves the needle along the scale.

The cubical expansion may be shown by a brass ball fitted exactly to a ring, so that when heated it no longer passes through the ring.

The expansion of liquids may be shown by a capillary glass tube terminating in a bulb. The latter being filled with some colored liquid, and heated, the liquid rises in the tube, and thus indicates the expansion. Such a tube and bulb are shown in Fig. 118.

In these experiments, the bodies contract to their former dimensions on cooling; but certain metals, especially zinc, form an exception to this rule, and also some kinds of glass.

II.—TEMPERATURE AND ITS MEASUREMENT.

185. The **temperature** of a body is the tendency to impart sensible heat to other bodies.

Temperature must not be confounded with quantity of heat. A body may have a high temperature, but possess a small quantity of heat, and *vice versa*. If a cup of water be taken from a boiling cauldron, both the water in the cup and that in the cauldron will have the same temperature; but, obviously, very different quantities of heat.

186. The **thermometer** is an instrument used for the measurement of temperature.

The senses can but imperfectly determine the effect of heat and cold (the absence of heat); hence, recourse is had to the effects definitely produced by heat on bodies, and particularly to *expansion*; but delicate measurements may be made by some of the electrical phenomena caused by heat. (See Art. 389.)

Liquids are best suited for use in the thermometer, since the expansion of solids is too small, and that of gases too great. Mercury and alcohol (colored) are the only liquids used; because the former boils only at a very high temperature, and the latter does not solidify at the greatest known degree of cold.



Fig. 118.



Fig. 119.

187. The **mercurial thermometer,** the most extensively used, consists of a capillary glass tube (*stem*), at the end of which is blown a *bulb*, forming a spherical or cylindrical reservoir. Both the bulb and a part of the stem are filled with mercury, and the expansion or contraction, caused by a change in the temperature, of the air or other fluid in which the bulb is placed, is measured by a graduated scale.

After the manufacture of the tube, the construction of a thermometer involves three important operations: the division of the tube into parts of equal capacity (*calibration*), the introduction of the mercury into the bulb, and the graduation. The first requires care, owing to the slight inequality in the bore of the tube; the second is accomplished by introducing the mercury and boiling it in the bulb, and then when the air in the tube has been expelled by the mercurial vapor, hermetically sealing it. In the graduation, two points must be first ascertained: the freezing-point and the boiling-point. The former is that at which ice melts, and the second that at which distilled water boils, the barometer standing at 760 millimeters, equal to 29.9 inches. The distance between these two points is the unit for measuring temperature, just as a yard or meter is used for measuring lengths. (See Fig. 119.)

188. **Scales.**—In Fahrenheit's scale (F.) the *freezing-point* is marked 32°, and the *boiling-point* 212°, the interval being divided into 180 degrees, and the scale continued above and below the fixed points. In the Centigrade scale (C.), the freezing-point is marked 0 (zero), and the boiling-point 100°, the space between divided into 100 degrees. In Reaumur's scale (R), the freezing-point is 0°, and the boiling-point 80°. Degrees below zero are indicated by the negative sign (−).

The scale of Fahrenheit is used in this country and England; the Centigrade, in France and other countries of Europe. Fahrenheit degrees may readily be converted into Centigrade, and *vice versa*. From the number of Fahrenheit degrees subtract 32, and $\frac{5}{9}$ of the remainder will be the number of Centigrade degrees; since 180° F. = 100° C. Or to $\frac{9}{5}$ of the number of Centigrade degrees add 32°, and the sum will be the corresponding Fahrenheit degrees.

The mercurial thermometer is the most valuable of all liquid thermometers, for mercury expands proportionally to the degree of heat between −36° and 100°. For temperatures below −36°, alcohol must be used; mercury becomes solid at −40°, and boils at 350°.

Alcohol boils at 78° C., or about 172° F., and hence the alcohol thermometer is unreliable for high temperatures; but for low temperatures it is very valuable, as alcohol does not solidify at the greatest known cold.

189. The **pyrometer** is an instrument used to measure very high temperatures—beyond the range of the mercurial thermometer.

Wedgewood's, Daniell's, and other pyrometers were constructed on the principle explained in Art. 183, and illustrated by Fig. 117. But such instruments have given place to other methods to be explained hereafter.

Table of Temperatures.—The following table gives some of the most important points of temperature, according to the Centigrade and Fahrenheit scales.

Greatest artificial cold.....	−140° C.	or	−220° F.
Greatest natural cold.....	−58.7	"	−73.7
Mercury freezes	−39.4	"	−39

Mixture of snow and salt.....	−20° C.	or	−4° F.
Greatest density of water.....	+4	"	+39.2
Blood heat.....	36.6	"	97.9
Alcohol boils	78	"	172¾
Water boils	100	"	212
Mercury boils.....	350	"	662
Sulphur boils	440	"	824
Silver melts.....	954	"	1749
Cast-iron melts.....	1530	"	2786

III.—EXPANSION OF BODIES BY HEAT.

190. **Expansion of Solids.**—The expansion of solids through the operation of heat has many applications in the arts. The following are illustrations.

The base of furnaces must be given play at the ends, otherwise the expansion will split the masonry; in the construction of railroads, a small space is left between successive rails; and water pipes are fitted together by means of telescope joints. If hot water is poured into a glass, it is apt to crack the glass, owing to the unequal expansion of the different parts. The force exerted by expansion through heat is enormous. In expanding a pound of iron, by an increase of temperature from 0° to 100° C., $\frac{1}{780}$ of its bulk, a force is exerted equal to 16,000 foot pounds, or sufficient to raise a weight of 7 tons through a height of one foot.

The contractile force is correspondingly great. An application of this is seen in the mode of tiring wheels. The tire, made red-hot, is placed on the wheel, and then cooled, so that by its contraction it may press the parts of the wheel together.

191. The **coefficient of expansion** is the degree of expansion which occurs in any of the three dimensions of a body when its temperature rises from 0° (zero) to 1°. The increase of the unit of volume under that change of temperature is the *coefficient of cubical expansion.*

In the case of a cube, the coefficient of cubical expansion is a little more than three times that of linear expansion.

192. The **compensation pendulum** is a beautiful application of the expansion of metals by heat. It is so constructed that the elongation caused by expansion is compensated, so that the distance between the center of suspension and the center of oscillation always remains the same, thus securing isochronous oscillations. (Art. 58.)

The gridiron pendulum (Fig. 120) is a common form of the compensation

pendulum. The frame-work supporting the ball L consists of alternate rods of steel and brass, the former being represented in the cut by shaded lines. These are so arranged that the elongation of the brass rods causes the ball to rise, while that of the steel rods tends to lower it.

There are other forms of compensation pendulums, among which Graham's mercury pendulum is one of the simplest and most useful. The ball of the pendulum consists of a glass cylinder containing a certain quantity of mercury; the upward expansion of which compensates the downward expansion of the steel rod supporting it. The same principle is applied in the construction of the *compensation balance* of watches and chronometers.



Fig. 120.

193. **Expansion of Liquids.**—When liquids contained in vessels are subjected to heat, there is an apparent loss of bulk, caused by the expansion of the containing vessel. This must be allowed for to obtain the coefficient of absolute expansion of the liquid.

The following experiment will illustrate this: Take a flask of thin glass, having a narrow stem, fill it with some colored liquid, and immerse it in hot water. The column of liquid in the stem at first sinks from *b* to *a* (Fig. 121), on account of the expansion of the flask, but almost immediately after rises, continuing to ascend until the temperature of the liquid in the flask is the same as that in the vessel.

There are many ingenious methods of determining the *coefficient* of expansion of liquids as well as solids. The following is a simple and beautiful contrivance for determining that of mercury in glass: The apparatus represented in Fig. 122 consists of a glass cylinder having a bent capillary stem open at the end. The apparatus is first weighed empty, and then when filled with mercury at zero; the difference, of course, showing the weight of the mercury. On being raised to a given temperature, the mercury expands, and a certain quantity passes out into a receiving vessel. This is carefully weighed. When the temperature is restored to zero, the mercury contracts, and leaves an empty space in the vessel, which represents the amount of contraction or expansion of the mercury remaining in the cylinder due to the change of temperature. This apparatus is sometimes called the *weight thermometer*, because the temperature may be deduced from the weight of the mercury that overflows.

The total apparent expansion of mercury is, between 0° and 100°, .01543; of

distilled water, .0466; of sulphuric acid, .06; of ether, .07; of nitric acid, .11; of alcohol, .116; of chloroform, .157. In order to find the absolute expansion of a liquid, it is requisite to add to the apparent expansion the expansion of the containing vessel.

The force which liquids exert in expanding is enormous. A pressure of 600 atmospheres would be required to prevent the expansion of mercury when it is heated from 0° to 10°.



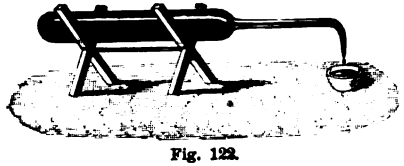
Fig. 121.

194. The **greatest density of water** exists at a temperature of 4° C. When its temperature sinks, it contracts until it reaches that point, and then it expands up to the freezing-point.

This is a fact of great importance in the economy of nature. The water of lakes and rivers cools at the surface by its contact with the cold air, and the colder water sinks to the bottom, thus causing a series of currents which continue until the whole reaches a temperature of 4°; then the water at the surface remains stationary, and the ice formed protects the water below at a temperature of 4°, which is not too low for animal life.

195. **Expansion of Gases.**—Gases are the most expansible of all bodies, and the most regular in their expansion. All have very nearly the same coefficient of expansion.

196. It has been ascertained by careful experiment that all gases have the same coefficient of expansion as air, and that this remains the same whatever be the pressure supported by the gas.


Fig. 122.

These two statements, or simple laws, are only approximately correct. They were deduced independently by Dalton and Gay-Lussac.

197. The **specific gravity, or density,** of a gas is the ratio of the weight of a certain volume of the gas to that of air, at a temperature of 0° C., and at a barometric pressure of 760 millimeters, equal to 30 inches (nearly).

To determine this a globe of about two gallons' capacity is used, the neck of which is provided with a stop-cock, which can be screwed to the air-pump. The

globe is first weighed empty, and then full of air, and afterward full of the gas in question. In this way the relative weights of the air and the gas are ascertained.

IV.—CHANGES OF CONDITION. VAPORS.

198. **Fusion.**—After a certain degree of heat has been reached, the attraction of cohesion is insufficient to hold the molecules together, and the solid becomes a liquid. This is called *fusion.*

All substances do not fuse under the action of heat, some being changed into gases, and decomposed. This is the case with paper, wood, coal, etc. Many bodies have proved incapable of fusion under intense heat, and hence are said to be *refractory.* In proportion as the means of producing higher temperatures have been reached, such substances have diminished in number. The temperature required for fusion is constant for each substance. Thus mercury fuses at −38.8° C.; oil of turpentine, at −27°; ice, 0°; butter, +33°; phosphorus, 44°; sulphur, 114°; tin, 228°; lead, 335°; silver, 954°; gold, 1,250°; iron, 1,500°; platinum, 1,775°.

Alloys are generally more fusible than any of the metals of which they are composed. For example, an alloy of five parts of tin and one of lead, fuses at 194°. Hence the use of fusible alloys in soldering, and taking casts. Steel melts at a lower temperature than iron, though it contains carbon, which is almost absolutely infusible.

199. **Latent Heat.**—From the moment fusion begins till it is complete, there is no change of temperature, although there is a constant supply of heat required and absorbed by the body. This heat, not being indicated by the thermometer, has been called *latent heat.*

The following experiment will illustrate this: Take a pound of water at 80° C., and mix it with a pound of water at zero, and the mixture will be found to be at 40°. Then take a pound of pounded ice at zero and mix it with a pound of water at 80°, and the result will be two pounds of water at zero. This shows that it takes as much heat to liquify a pound of ice as is required to raise a pound of water from zero to 80°. This is the latent heat of the fusion of ice.

During *solution*, as well as during fusion, a certain quantity of heat always becomes latent, and consequently there is a diminution of temperature. When a chemical combination takes place, as when caustic potash is dissolved in water, there is often an increase in temperature.

Solidification, or *congelation*, occurs under laws similar to those of fusion: all bodies solidify at a certain temperature, which remains constant from the beginning to the end of the process. The latent heat becomes free at the moment of solidification.

200. **Crystallization** takes place in bodies that pass slowly from the liquid to the solid state; that is, they assume regular geometrical forms, such as the cube, prism, etc., called *crystals.*

Snow, ice, and many salts present examples of crystallization. The crystallization is said to take place by the *dry way*, when the crystals are formed from a body in fusion; and in the *moist way*, when it takes place from the slow evaporation of a solution.

The freezing of water is effected by various circumstances. For example, a very rapid agitation prevents the formation of ice. Despretz was able to lower the temperature of water contained in capillary tubes to −4° F., without congelation. This shows how the sap of plants, contained in fine capillary vessels, is protected from freezing even during severe cold.

The expansive force produced by the formation of ice is enormous, as shown in the bursting of water-pipes, the breaking of jugs, etc. This is the most powerful agent in disintegrating the earth's surface, splitting stones and rocks, and breaking up the soil, as the water penetrates the pores of the ground and freezes. Major Williams, in Canada, filled a 13-inch bomb-shell with water, firmly closed the touch-hole with an iron plug weighing three pounds, and then exposed it to the frost. After some time the iron plug was forced out with a loud explosion, and thrown to a distance of 415 feet, while a cylinder of ice eight inches long issued from the opening.

Cast-iron, bismuth, and antimony expand on solidifying, like water, and hence can be used for casting; but gold, silver, and copper contract; and, therefore, coins of these metals cannot be cast, but must be stamped with a die.

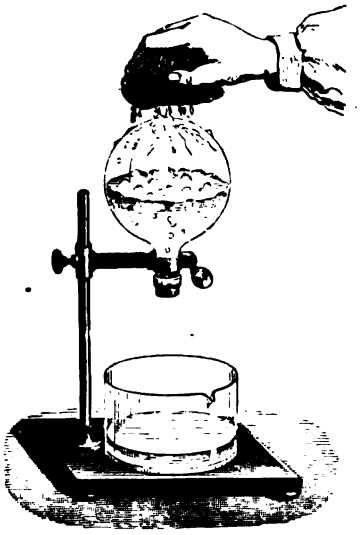


Fig. 123.

201. **Vapors** are fluid substances into which liquids such as ether, alcohol, water, and mercury pass under the influence of heat. The passage of a liquid into the aeriform state is called *vaporization;* the slow production of vapor at the surface of a liquid, *evaporation;* and the rapid conversion of a liquid into vapor, forming bubbles below the surface, *ebullition*, or *boiling*.

Liquids that pass into vapor are called *volatile liquids;* those which do not form vapors without being decomposed, *fixed liquids*, such as the fatty oils. Ice, arsenic, camphor, and generally the odoriferous solids, pass directly into vapor, without assuming the liquid state. Vapors are formed more freely in a vacuum, because they are relieved from the pressure of the air.

The temperature required for ebullition varies with the pressure; and as soon as boiling begins, the temperature of the liquid remains the same.

Under a barometric pressure of 30 inches (760 millimeters), the *boiling-point* of carbonic acid is −82° C.; of ether, 37°; alcohol, 78°; distilled water, 100°; turpentine, 157°; phosphorus, 290°; mercury, 358°.

To show that the boiling-point is lower under diminished pressure, place a small dish containing water at 30° under the receiver of the air-pump; and after exhaustion, the liquid will soon begin to boil. Owing to reduced air-pressure, water boils on Mont Blanc at 84° C., or about 183° F.

This relation between the boiling-point of water and atmospheric pressure dependent upon height, affords a method of determining elevations above the surface of the earth; since, when we know at what temperature water boils at a

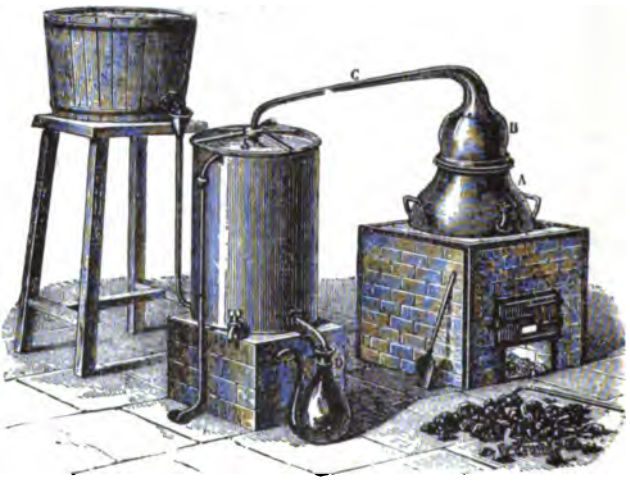


Fig. 124.

particular place, we can determine the pressure, and from this deduce the height. An ascent of about 1,080 feet causes a reduction of 1° C. in the temperature required to boil water.

The following interesting experiment illustrates the above principle: Take a glass flask as represented in the cut (Fig. 123), and boil some water in it; and after the steam has expelled the air, cork it, and invert it. Now, if the steam filling the space above the water be condensed by pouring cold water upon the flask, the water will begin to boil again, on account of the partial vacuum thus created.

202. **Distillation** is the process of separating a volatile liquid from substances which it holds in solution, or two liquids of different degrees of volatility.

The apparatus employed is called a *still*, and consists of three principal parts: the *body* A (Fig. 124), a copper vessel containing the liquid, which fits in the

furnace; the *head* B, fitting on the body, with a lateral tube, C, and the *worm* S, a long spiral tin or copper tube placed in a cistern kept full of cold water, so as to condense the vapor passing through the worm.

Water is distilled in order to free it from the many impurities which it contains. The vapor is condensed in the worm, and after condensation the distilled water flows into a receiving vessel, D. In order to keep the worm immersed in cold water, a supply enters at the bottom of the cistern as fast as the heated water runs out by a tube at the top, as shown in the figure.

203. The hygrometer is an instrument for determining the quantity of watery vapor contained in a given volume of air.

The quantity of vapor in the air is always changing. While the atmosphere is never completely saturated, it is never entirely dry. The absolute moisture is measured by the weight of water in the form of vapor contained in a unit of volume. It varies with the temperature. In summer there is a maximum at 8 o'clock A.M., and a minimum at 3 P.M. and 3 A.M., because the ascending current of air carries the moisture upward. It is in excess within the tropics, and is greater in the central regions of a continent than near the sea coast.

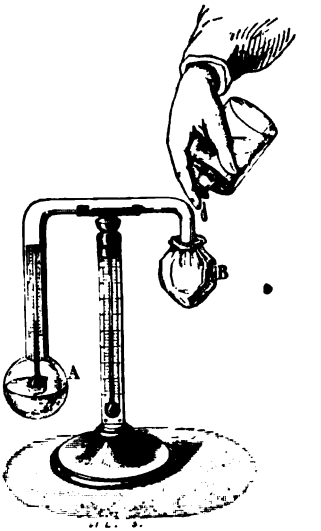


Fig. 125.

Hygrometers are of various forms. Daniell's hygrometer consists of two glass bulbs at the extremities of a glass tube bent twice (Fig. 125). The bulb A is two-thirds full of ether, and a very delicate thermometer plunges into it; the rest of the space contains nothing but the vapor of ether, the ether having been boiled before the bulb B was sealed. This bulb is covered with muslin, and ether is dropped upon it, which in evaporating cools the bulb, and thus causes the vapor contained in it to be condensed. The ether in A, on account of the reduced tension, then begins to form vapor, which passes over to the other bulb. Thus the ether becomes cooled; and when the temperature of the air in immediate contact with it sinks below the point required to retain the vapor, it is deposited on the outside, and this degree of temperature is indicated by the thermometer in the inside, which being compared with the temperature of the air as shown by the outside thermometer, indicates the *hygrometric state*, or *degree of saturation*, of the air. The degree of temperature at which moisture is deposited is called the *dew point*. In determining this point it is usual to reverse the above process, discontinuing the dropping of ether on the bulb B, and allowing the temperature of A to rise. The temperature at which the deposition of dew ceases is then observed, and the mean of this and the temperature, previously observed, at which

the dew commenced, is taken as the dew point. This deposition of moisture, called *dew*, is caused by a condensation of the watery vapor in the air in contact with a cold surface.

V.—TRANSMISSION OF HEAT.

204. Heat may be transmitted by radiation, conduction, or convection.

205. The **radiation** of heat is its transmission from one body to another through the air, as if by rays.

When we stand at a little distance from a fire, or other source of heat, we experience a sensation of warmth, caused by the radiation of heat, which is not transmitted by the air but through it, and without directly affecting the temperature of the air. It is in this manner that the heat of the sun reaches us.

206. The **conduction** of heat is its transmission in the mass of a body, from one part to another.

Thus when the end of a metal bar is heated, the increase of temperature extends itself along the whole bar.

207. Bodies in which the heat is readily conducted, such as the metals, are called *good conductors;* while those in which the heat passes slowly, or with difficulty, from one part to another, are called *bad conductors.* Such are resinous substances, also glass, wood, and all liquids and gases.

Organic substances are bad conductors. Woods conduct better in the direction of their fibres than across them. This feeble transverse conduction serves to protect trees from sudden changes of temperature. The conducting power of the bark is less than that of the body of the tree. Cotton, wool, straw, bran, etc., are all bad conductors.

That liquids are bad conductors may be shown by a very simple experiment: Take a long test-tube, and having half filled it with water, place a piece of ice in it in such a way that it cannot rise to the surface. Then, by inclining the tube and heating the surface of the liquid by means of a spirit lamp, the liquid may be made to boil without melting the ice.

All substances of loose structure, having air between their particles, offer great resistance to the propagation of heat. Thus straw, wool, furs, feathers, eider-down, etc., are bad conductors.

208. The **convection** of heat, in liquids and aëriform bodies, is its conveyance from one part to another by means of the currents formed in the mass by heating its lower portion.

In order to increase the temperature of a liquid contained in a vessel, the heat is applied to the bottom. This causes an expansion of the inferior layers, which therefore rise, while the colder and denser parts descend. These currents

can be rendered visible by putting some light substance, as bran, into the water, as shown in Fig. 126.

In heating the air of a room, the same principle acts. The register supplying heated air, the stove, or steam radiator, is placed near the floor, so that the hot air may ascend, and cause a descent of the colder air, which is heated in its turn. Ventilators, on the other hand, to let out the warm, vitiated air, should be placed near the ceiling.



Fig. 126.

209. The **sensation** of heat or cold which we experience when in contact with various bodies arises from the conduction of heat. Good conductors, as the metals, feel cold because they readily conduct heat from the person; bad conductors, as wood, flannel, etc., feel warm, because they conduct very slightly.

Substances that are bad conductors when used as clothing confine the heat of the person, and hence keep us warm; but good conductors take the heat from the person. Hence in the summer, the latter substances are used for clothing.

A burning piece of wood can be held in the hand close to the burning part, while a piece of iron heated at one end cannot be held at the other unless it is of considerable length. Water will boil sooner in a metallic vessel than in one of porcelain, because the former is a better conductor.

210. **Radiant heat** is heat transmitted by radiation, in rays similar to the rays of light. Such a ray is sometimes called a *thermal ray*, or *calorific ray*, to distinguish it from a luminous ray. Some calorific rays are luminous, others obscure. Bodies of all temperatures radiate heat.

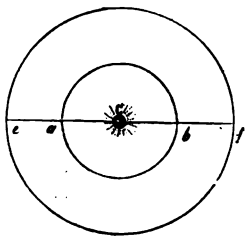


Fig. 127.

211. The **laws of radiation** are: 1. Radiation takes place in all directions round a body. 2. In a homogeneous medium, radiation takes place in a right line. 3. Radiation takes place in a vacuum as well as in air.

212. The **intensity of radiant heat** varies inversely as the square of the distance from its source, and the obliquity of the rays to the radiating surface.

Suppose in a hollow sphere *a b* (Fig. 127) the source of heat is the center, C; then each unit of surface in the interior receives a certain quantity of heat.

Now a sphere *e f*, of double the radius, will present a surface four times as great, because the surface of a sphere increases as the square of its radius. But the same quantity of heat is emitted, and therefore each unit of the surface of *e f* can receive only one-fourth as much.

213. When thermal rays fall upon a surface they are partly absorbed and partly reflected. When the rays of heat are reflected, the angle of reflection is equal to the angle of incidence.

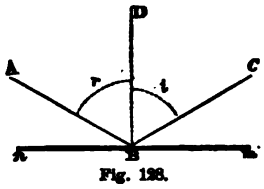


Fig. 128.

If *m n* (Fig. 128) be a plane reflecting surface, C B an *incident ray*, B D a line perpendicular to the surface (called the *normal*), and B A the reflected ray; the angle C B D (angle of incidence) is equal to the angle A B D (angle of reflection).

The proportion of heat reflected compared with the quantity received varies with different substances. The following table shows this for several substances, the angle of reflection being 50°:

Silver plate	0.97	Steel	0.82
Gold	0.95	Zinc	0.81
Brass	0.93	Iron	0.77
Platinum	0.83	Cast-iron	0.74

214. The absorbing power is always inversely as the reflecting power. The reflected and absorbed heat is not, however, exactly equal to the incident heat, since a part is irregularly reflected in various directions. This is called *scattered or diffused heat.*

Lamp-black and white lead have the greatest absorbing power; other substances have it in the following proportions:

Lamp-black	100	Indian ink	85
White lead	100	Shellac	72
Isinglass	91	Metals	18

The radiating power is equally various, as the following table will show: *

Lamp-black	100	Tarnished lead	45
White lead	100	Mercury	20
Paper	98	Polished lead	19
White glass (common)	90	Polished iron	15
Isinglass	80	Tin, gold, silver, copper, etc.	12

215. The radiating and absorbing powers of a body are equal; and, therefore, any cause which affects the one produces a corre-

* These are the determinations of Leslie, but some French physicists have reached conclusions that indicate a less radiating power for the metals.

sponding effect on the other. It also affects in an inverse degree the reflecting power.

These powers are modified by the degree of polish, the density, and the thickness of the radiating substance, by the obliquity of the incident or emitted rays, and by the nature of the source of heat.

The absorbing power is greatest when the rays are at right angles, and diminishes as they deviate from that direction. This is the principal cause of the difference of temperature in summer and in winter, the sun's rays being less oblique in the former than in the latter.

The *polished* fire-irons before a fire are often cold, while the *black* fender is unbearably hot, because the polished surface does not absorb like the black one. But, if a liquid is to be kept hot as long as possible, it must be placed in a brightly polished metallic vessel, since there is less radiation from such a substance. The surface of a stove should be black, but that of pipes to convey heat should be bright.

216. **Diathermancy** is that property of bodies by virtue of which



Fig. 129.

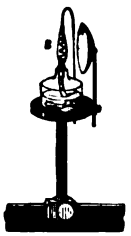


Fig. 130.

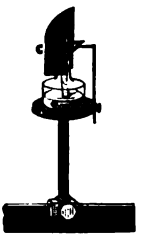


Fig. 131.



Fig. 132.

they permit the calorific rays to pass through them. The power of stopping radiant heat is called *athermancy*.

The former corresponds to *transparency* in reference to light; the latter, to *opacity*. But transparent substances do not necessarily possess diathermancy. Among solids, smoky quartz, which is nearly opaque to light, transmits heat very well; while alum, which is perfectly transparent, cuts off 88 per cent of heat rays; and ice is still more diathermanous. The liquids, except olive oil, are all colorless and transparent, and yet vary as much as 75 per cent in the amount of heat which they transmit.

The diathermancy of bodies differs greatly with heat from different sources. The Italian physicist Melloni in his experiments used five sources of heat: 1. Locatelli's lamp, that is, one without a glass chimney, but provided with a re-

flector (Fig. 129); 2. An Argand lamp—one with a chimney and a double draught; 3. A platinum spiral kept red-hot by a spirit lamp (Fig. 130); 4. A blackened copper plate kept at a temperature of about 400° by a spirit lamp (Fig. 131); 5. A copper tube blackened on the outside and filled with water at 100° (Fig. 132).

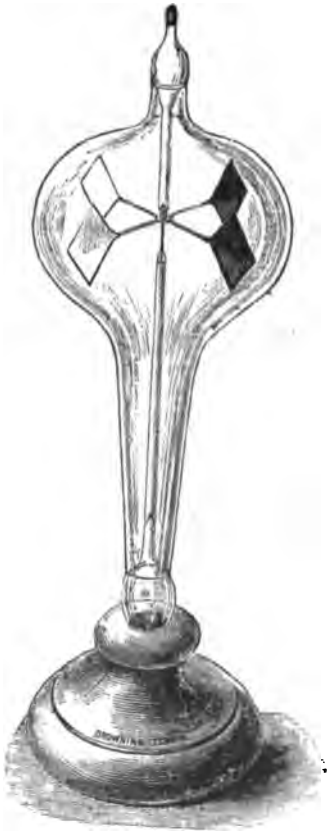


Fig. 133.

Rock salt is diathermanous for all kinds of heat, as white glass is transparent for light from all sources. Fluor spar transmits 78 per cent of the rays from Locatelli's lamp, but only 33 of those from a blackened surface at 100°. Ice transmits 6 per cent of the rays from Locatelli's lamp; 0.5 per cent of those from an incandescent platinum wire, and none from the other sources. It has been proved by Tyndall and others that as the temperature of the source of heat rises, a great proportion of heat is transmitted.

It is in consequence of the great diathermancy of dry air, that the higher regions of the atmosphere are so cold, notwithstanding the great heat which traverses them. In gardens, the use of shades to protect plants depends partly on the diathermancy of glass for heat from luminous rays, and its athermancy for obscure rays. The heat which emanates from the sun by contact with the earth is changed into obscure heat, and cannot pass back through the glass; hence the heat is accumulated below the shade.

217. The **radiometer** is an instrument invented by William Crookes, of England, to show the action of radiant light and heat.

This apparatus (Fig. 133) consists of a glass tube with a bulb blown on it, which is fused at the bottom to a glass tube, resting on a wooden support. Within the tube, at its upper end, is fused a fine steel point, on which rests a small vane consisting of four arms of aluminium wire fixed at one end to a small cap, while at the others are small lozenge-shaped discs of thin mica coated on one side with lamp-black. The entire weight of the vane is not more than two grains. In order to keep it on the pivot a tube is fused into the upper part of the bulb, which reaches down to, and just surrounds, the top of the cap, but without touching it. The tube having been exhausted of air is sealed at the lower point. When a body emitting light or heat is brought near the instrument, the vane is made to

rotate, showing that it is acted upon by a mechanical force. This has been attributed to the action of the luminous or heat ray; but, as the vacuum is not perfect, it has also been imputed to currents in the rarefied air produced by the unequal heating of the black and white disks of the vane. Many interesting researches have been conducted by means of this ingenious instrument.

VI.—CALORIMETRY.

218. **Calorimetry** is the measurement of the quantity of heat which a body parts with or absorbs, when its temperature sinks or rises through a certain number of degrees, or when it changes its state—solid, liquid, or gaseous.

The quantity of heat can be expressed only by such of its effects as can be measured. It is usually defined by its capability of raising a given quantity of some substance, as water, to a certain degree of temperature. This is called a *thermal unit;* which is the *quantity of heat required to raise one pound of water through one degree, Centigrade.*

219. The **specific heat** of a body is the quantity of heat which it absorbs when its temperature rises through a given number of degrees (from zero to 1°, for example), compared to the quantity of heat which would be absorbed, under the same circumstances, by the same weight of water.

Thus, when we say that the specific heat of lead is 0.0314, we mean that the quantity of heat which would raise the temperature of any given weight of lead 1° C., would raise the temperature of the same weight of water only .0314° C.; in other words, the quantity of heat that would raise the temperature of one pound of water 1°, would raise one pound of lead about 32° (1 ÷ .0314).

So also in cooling: water requires a much longer time to cool to a certain temperature, and gives out more heat. If a pound of mercury at 100° be mixed with a pound of water at zero, the temperature of the mixture will be about 3°. Thus, while the mercury has cooled through 97°, the water has been raised only 3°; showing that water requires about 32 times as much heat as mercury to cause the same rise of temperature.

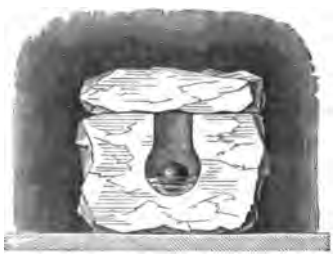


Fig. 134.

There are various methods employed to measure the specific heat of a body, of which that of the melting of ice affords an illustration. This is based on the fact that to melt a pound of ice, about eighty thermal units are necessary. In Black's *calorimeter*, a cavity is made in a block of ice, into which the body, heated

to a certain temperature, is placed, and covered. (See Fig. 134.) After the body has been cooled to zero, it is taken out, and wiped dry with a sponge, which has been previously weighed; the water in the cavity being also absorbed by the sponge. The increase of weight in the sponge represents the quantity of ice which has been converted into water, and becomes the measure of the specific heat of the body examined. There are other forms of the calorimeter, various in construction.

Latent heat has already been referred to (Art. 199). It differs very greatly in different bodies. The following shows the latent heat of fusion of several substances:

Water	79.24	Tin	14.25
Zinc	28.13	Sulphur	9.37
Platinum	27.18	Lead	5.37
Silver	21.07	Mercury	2.83

These numbers represent the degrees, Centigrade, through which a pound of water would be raised by the heat evolved by a pound of the body in question in passing from the liquid to the solid state, or the number of pounds of water which could be raised 1° C. by the solidification of these bodies, respectively. It requires about 142° F. to convert a pound of ice at 32° F. into water, the temperature of which will still be 32°; showing that 142° F. of *sensible* heat becomes *latent* in the process of fusion.

This heat, though latent, is not lost, being consumed in moving the atoms into new positions. Thus it does a certain kind of *work*, which is analogous to the raising of a weight. When the liquid solidifies, the heat is reproduced, just as when a body falls to the ground, it produces by its impact the heat, which represents the amount of work that was required to raise it.

There is also the *latent heat of vaporization*, that is, heat that disappears in converting a liquid into vapor.

VII.—THE STEAM-ENGINE.

220. **The steam-engine** is a machine in which the elastic force of steam is used as the motive power In the ordinary kind, the alternate expansion and condensation of steam imparts to a piston an alternating rectilinear motion, which is changed into a circular motion by various mechanical contrivances.

In describing the steam-engine, the apparatus required to produce the steam is first to be considered. This consists of the boiler and its appurtenances (Fig. 135). The boiler is a large wrought-iron cylinder, P Q, with curved ends, beneath which, and connected with it by two tubes, are two smaller cylinders, B B, called *heaters*, which are filled with water, the boiler being only about half full. (The cut shows only one of these.) Below these the flames and heat of the fur-

nace are made to sweep back and forth, by the draught of the chimney K, usually very high.

S is the *safety valve*, a conical lid fitted into an orifice in the boiler, and held down by a lever, so weighted that it may be lifted by a certain pressure, allowing the valve to open and the steam to escape, thus reducing the pressure.

The safety whistle, *s*, is regulated by the float E, which when the water descends below a certain level in the boiler, opens the aperture, and the steam

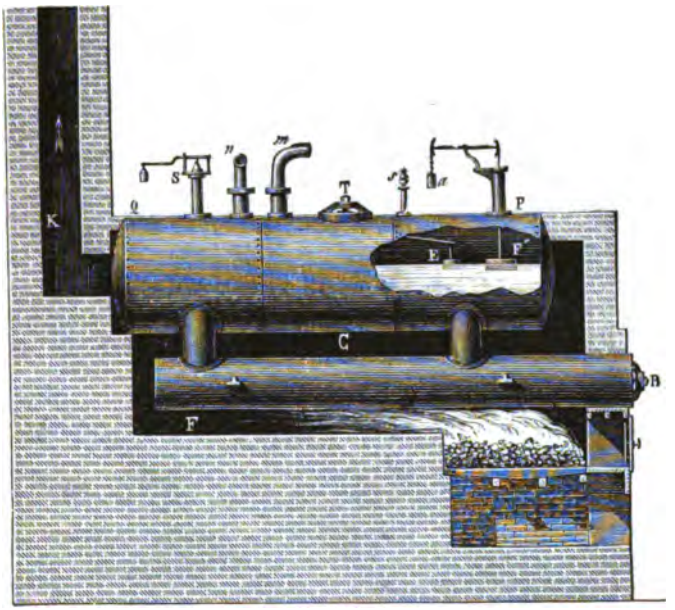


Fig. 135.

escaping blows the whistle, and thus gives an alarm. F′ is a float which shows the height of the water by its action on the lever and weight *a*. Any deviation of this from the horizontal position indicates a deficiency or excess of water in the boiler.

T is the *man-hole*, an aperture by which the boiler may be entered and cleaned. This is self-closing, by a cover that fits against the inside edges, held in position by a screw. Thus the greater the pressure of the steam, the more tightly is this aperture closed.

The *double-action engine*, or *Watt's engine*, is shown in Fig. 136. On the left is the *cylinder*, which receives the steam from the boiler. Through the part represented to be broken away, the piston P may be seen, which is moved up and down by the pressure of the steam alternately below and above. By the piston-rod A this motion is communicated to a large iron lever, L, called the beam,

which transmits the motion to a connecting-rod, I, working on a crank, K, to which it imparts a continuous rotatory motion. The crank is fixed to a horizontal *shaft*, which turns with it, and, by means of wheels or endless bands, sets in motion machinery; or in steam vessels turns the paddle-wheels, or propelling screw.

On the left of the cylinder is a valve-chest, where the steam is admitted alternately above and below the piston; and after its action on the piston, it passes into a vessel called the *condenser* O, into which cold water is injected.

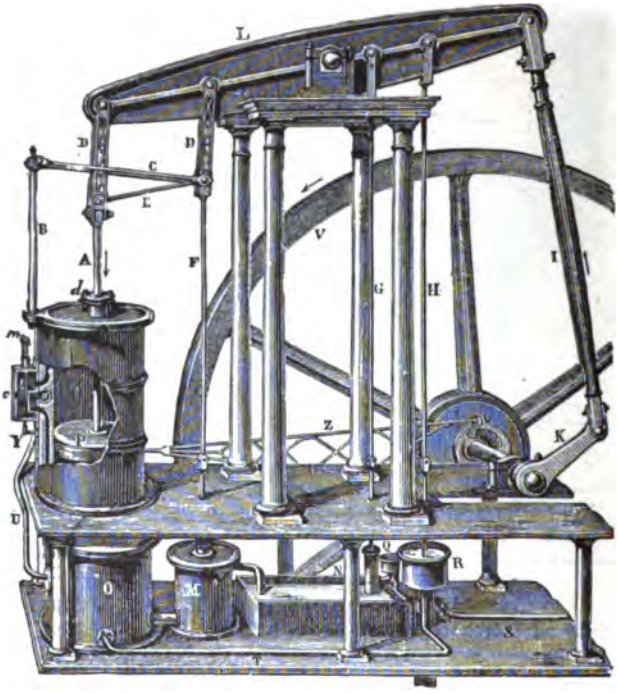


Fig. 136.

Thus the force of the steam is withdrawn from each chamber of the cylinder, after its work is done, leaving the pressure on the other face of the piston free to act. M is an *air-pump*, used to withdraw from the condenser the heated water which it contains, and also the air which was dissolved in the water of the boiler. Q the *feed-pump* forces the heated water into the boiler; and R, a cold-water pump supplies the condenser. V is a large iron wheel, called the *fly-wheel*, which by its inertia gives steadiness to the motion.

The supply of steam to the cylinder is usually regulated by an ingenious contrivance called the *governor*, which consists of two heavy balls connected by

jointed rods to a revolving axis, and so adjusted that when the steam is too copious it causes the balls to revolve rapidly, and by the centrifugal force to fly apart, thus pulling down a collar, which by means of a lever acts upon a valve, and controls the supply of steam.

221. Steam engines are of two kinds : *low pressure* and *high pressure engines.* Low pressure engines are mostly condensing engines; high pressure engines, not having a condenser, force the steam, after it has moved the piston, into the air; consequently the pressure must exceed that of the atmosphere. Of the latter, the locomotive is an example.

High pressure engines are usually worked by a pressure of from fifty to sixty pounds to the square inch of the piston; and of this fifteen pounds must be used in overcoming the pressure of the atmosphere.

VIII.—SOURCES OF HEAT.

222. The **sources of heat** are (1) *mechanical,* as friction, percussion, and pressure; (2) *physical,* as solar radiation, terrestrial heat, molecular action, changes of condition, and electricity; and (3) *chemical,*—molecular combinations, more especially combustion.

Friction produces intense heat, as is seen in the case of car wheels. By rubbing together two pieces of ice in a vacuum below zero, Sir Humphrey Davy par-

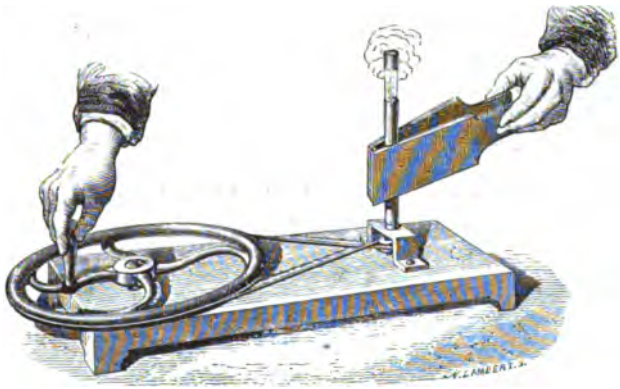


Fig. 137.

tially melted them. In boring a brass cannon, Rumford found that the heat developed in 2½ hours was sufficient to raise 26½ pounds of water from zero to 100°, equal to 2,650 thermal units.

The following experiment, devised by Prof. Tyndall, demonstrates the production of heat by friction. A brass tube partly filled with water, and stopped

with a cork, is pressed within a wooden clamp and made to rotate rapidly by means of a band, which passes round a small wheel attached to the tube, and a large wheel, so that the small wheel and tube make several turns to one of the large wheel (Fig. 137). The tube is heated by the friction, and when the heat communicated to the water raises the temperature to the boiling-point, the cork is forced out.

The *pneumatic syringe* (Fig. 58, page 67) illustrates the production of heat by compression. At the bottom of the glass tube is a cavity containing a small piece of cotton moistened with ether or bisulphide of carbon; and when the air-tight piston is plunged down the tube, the heat caused by compressing the air ignites the cotton.

The *powder ram* for pile driving is constructed on the same principle. Upon the pile to be driven is fixed a powder mortar, into which fits an iron rammer. Gunpowder is placed in the mortar, and the rammer is allowed to fall into the mortar, condensing the air, and thus exploding the powder, which forces the rammer upward into its position before the fall, and by reaction, combining with the weight and percussion of the rammer, drives the pile downward.

In firing shot at an iron target, a sheet of flame is frequently seen at the moment of impact; and iron shells are sometimes exploded by striking against an object. This illustrates the production of heat by *percussion*.

223. **Solar radiation** is the most intense of all sources of heat. The heat emitted by the sun is equal to that produced by the combustion of 1,500 pounds of coal every hour on each square foot of its surface.

As the earth presents but a very small surface to the solar rays, it receives only an infinitesmal portion of the heat thus emitted—less than the two-billionth part. A French physicist (Pouillet), by means of what he calls a *pyro-heliometer*, has estimated the annual supply of solar heat received by the earth to be equal to the quantity required to melt a layer of ice all over the earth 35 yards thick.*

224. **Terrestrial heat** is the heat which the earth possesses of itself. This is observed to increase in mines and artesian wells with the depth penetrated.

The *layer of constant temperature*, beyond which the solar heat does not penetrate, varies in depth at different parts of the earth; below it, the temperature rises about 1° C., for every 90 feet, on the average. Hot springs and

* "Helmholz considers that the heat of the sun was produced originally by the condensation of a nebulous mass, and is kept up by a continuance of this contraction. A sudden contraction of the primitive nebular mass of the sun to its present volume would produce a temperature of 28 millions of degrees, Centigrade; and a contraction of one ten-thousandth of its mass would be sufficient to supply the heat radiated by the sun in 2,000 years. This amount of contraction could not be detected even by the most refined astronomical methods."—*Ganot.*

volcanoes are evidences of the internal heat of the earth, which is accounted for by the theory that our globe was once a highly heated liquid mass, which has cooled by degrees, the surface solidifying into a crust, now supposed to be about 40 or 50 miles thick.

225. **Chemical combinations** are generally accompanied by an elevation of temperature. The combination of oxygen with other substances, attended with the evolution of light and heat, is called *combustion.*

In ordinary combustion, the carbon of the coal, oil, or other burning substance, unites with the oxygen of the air; but combustion may take place without oxygen, as when phosphorus unites with chlorine. The union of any substance with oxygen is called *oxidation.* When oxidation is slow, as when iron rusts in the air, the heat is imperceptible; but when rapid, it becomes combustion.

Some substances, such as phosphorus, burn at the ordinary temperature of the air; but usually they do not unite with the oxygen of the air until their temperature is greatly raised. As soon as they ignite, the combustion goes on rapidly, in proportion to the supply of oxygen. In pure oxygen, substances burn that otherwise are entirely incombustible, glowing with the most intense light and heat.

226. A **flame** is a quantity of gas or vapor raised to a high temperature by combustion.

The illuminating power of flames is due to the presence of incandescent particles of carbon. A pure hydrogen flame gives out intense heat but scarcely any light.*

Animal heat is due to the processes of oxidation continually going on in the system; for oxygen passes through the lungs into the blood, and so into all parts of the body. This oxidation is more rapid when the body is exercised, and consequently there is a greater quantity of heat evolved. Oxidation is not connected with vegetation, except in the blossoming of plants, which is attended with an increase of temperature, sometimes quite appreciable, as in the *Victoria regia.* †

* "The heat produced by the chemical combination of two elements may be compared to that due to the impact of bodies against each other. Thus the action of atoms of oxygen, which, in virtue of their progressive motion and of chemical attraction, rush against ignited carbon, has been likened by Tyndall to the action of meteorites which fall into the sun."—*Ganot.*

† The *Victoria regia* is a plant which resembles the white water lily, found growing in the waters of the Amazon River and some other parts of South America. Its floating leaves attain a diameter of four or five feet, and its white and rose-colored blossoms, which rise from amongst the leaves upon prickly stalks, are sometimes twenty-three inches in diameter. Its fruit is a large spherical capsule filled with farinaceous seeds, which afford a nutritious and agreeable article of food.

SYNOPSIS FOR REVIEW.

HEAT, OR PYRONOMICS.

I.—NATURE AND GENERAL EFFECTS OF HEAT.

1. Definition of heat.
2. Theories as to its cause: 1. Of emission. 2. Of undulation.
3. Correlation of heat and mechanical force.
4. General effects.
 1. Internal work: 1. Raising temperature. 2. Expansion. 3. Change of state. (Expansion: 1. Linear. 2. Superficial. 3. Cubical.) (Solids.)
 2. External work—Overcoming atmospheric pressure.

II.—TEMPERATURE AND ITS MEASUREMENT.

1. Temperature, defined; distinguished from quantity of heat.
2. Thermometer: 1. Alcoholic. 2. Mercurial.
3. Thermometric scales: 1. Fahrenheit. 2. Centigrade. 3. Reaumur.
4. Pyrometer.

III.—EXPANSION OF BODIES BY HEAT.

1. Of solids.—Illustrations.
 1. Co-efficient of expansion.
 2. Compensation pendulum.—Gridiron pendulum.
2. Of liquids. Co-efficient of expansion. Greatest density of water.
3. Of gases. Co-efficient of expansion. Specific gravity of a gas

IV.—CHANGES OF CONDITION, DUE TO HEAT.

1. Fusion.
2. Crystallization.
3. Vaporization: 1. Evaporation. 2. Ebullition.
4. Distillation.
5. The hygrometer.

V.—TRANSMISSION OF HEAT.

1. Radiation: 1. Laws of. 2. Radiant heat. 3. Radiometer.
2. Conduction.
3. Convection: 1. In liquids. 2. In gases.
4. Reflection and absorption of heat.—Diathermancy.

VI.—CALORIMETRY.

1. Specific heat.—Measurement of.
2. Latent heat: 1. Of fusion. 2. Of vaporization.
3. Calorimeter—Black's.

VII.—THE STEAM-ENGINE: 1. High pressure. 2. Low pressure. } Construction.

VIII.—SOURCES OF HEAT.

1. Mechanical: 1. Friction. 2. Compression. Pneumatic syringe.
2. Physical: 1. Solar. 2. Terrestrial.
3. Chemical.—Combustion.

APPLICATION OF PRINCIPLES.

Explain the following: 1. Why the savage can obtain fire by rubbing two sticks together. 2. Why ice is formed only at the surface of the water. 3. Why, in constructing a railroad, the ends of the rails are placed a short distance apart. 4. Why pipes used to conduct heat are made of bright tin. 5. Why those used to carry off smoke are of dark iron. 6. Why iron becomes hot when it is hammered. 7. Why water boils at a certain temperature. 8. What causes the snapping of green wood when it is burning. 9. Why stoves are made of dark unpolished iron.

10. Why a blackened stove gives out more heat than a polished one. 11. Why a mercurial thermometer cannot be used in very cold regions to indicate the extreme cold of the atmosphere. 12. Why the handles of tea-pots are made of wood. 13. Why the air will not deposit moisture (dew) on an iron surface. 14. Why woolen garments are worn in the winter. 15. Why cotton or linen garments are more comfortable in the summer. 16. Why a piece of marble or metal feels, in the same atmosphere, colder than a piece of wood. 17. Why water-pipes sometimes burst in the winter. 18. Why solder is made of an amalgam of tin rather than of pure metal. 19. What makes steam a peculiarly efficient heating agent.

20. Why steam is more efficient than water at the same temperature. 21. Why running water does not freeze as readily as stagnant water. 22. Why the soil is broken up by the frost. 23. How it is that snow protects the soil from severe frost. 24. Why copper cannot be cast into moulds, like iron. 25. Why water boils at a lower temperature at great elevations. 26. Why in summer there is less moisture in the air in the afternoon than in the morning. 27. Why heat is admitted into the lower parts of a room. 28. Why openings into ventilators are placed in the upper part of the walls. 29. Why straw is used to protect plants from the frost.

30. Why it is colder on the tops of mountains than at the general surface of the earth. 31. Why wool, furs, and feathers, are bad conductors of heat. 32. Why, in boiling water, the heat is applied to the bottom of the vessel. 33. Why a person can hold a burning stick near the heated point, and not a rod heated at one end. 34. Why the solar rays give out more heat in the summer than in the winter. 35. Why, in digging wells, the heat increases with the depth. 36. Why burning carburetted hydrogen (carbon and hydrogen) gives out more light than pure hydrogen. 37. Why exercise increases the heat of the animal system. 38. Why water boils more rapidly in a metallic than in a porcelain vessel. 39. Why carpeted floors are warmer then bare floors.

40. Why double windows effectually protect a building from cold. 41. Why two garments are warmer than a single one of the same material and of a thickness equal to the two together. 42. Why window panes do not exclude the solar heat, while they confine the heat of the room. 43. Why a good fire-screen can be made of glass. 44. Why black clothes should not be worn in the summer. 45. Why the fire-irons are made of polished metal. 46. Why tea-pots are made of polished metal. 47. Why the air feels particularly chilly during a thaw. 48. Why a moist atmosphere is oppressive in hot weather, and raw and chilly in cold weather. 49. Why ice is preserved from melting by being wrapped in flannel. 50. Why a pitcher of cold water sweats in hot weather. 51. Why water, in a heated atmosphere, may be cooled by wrapping around the pitcher a wet cloth. 52. Why water boils more quickly in a vacuum than when exposed to the air. 53. Why the continued application of heat to melting ice does not raise its temperature. 54. In what way the application of a cold liquid may be made to produce the phenomenon of ebullition.

CHAPTER VII.

LIGHT.

I.—ORIGIN, TRANSMISSION, AND INTENSITY OF LIGHT.

227. **Light** is the agent which, by its action on the eye, excites in us the sensation of vision. That part of physics which explains the properties of light is called *optics*.

228. The two most noted theories advanced to explain the origin of light are the *emission or corpuscular theory* and the *undulatory theory*. The former conceives light to be an imponderable substance consisting of exceedingly minute particles, which are propagated with immense velocity; the latter, that it is caused by vibrations in the *luminiferous ether*, a subtle elastic medium filling all bodies, as well as the celestial spaces.

The emission theory was supported by Sir Isaac Newton; the undulatory theory, the principles of which were enunciated by Huyghens and Euler, has been adopted by most modern physicists. It not only explains the phenomena of light, but accounts for the connection between these phenomena and those of heat, both being analogous to those of sound.*

229. **Luminous bodies** are those which emit light, such as the sun and ignited bodies. Bodies through which the light is transmitted, so that objects can be distinguished through them, are said to be *transparent*, or *diaphanous*. Those that transmit light imperfectly, so that objects are not visible, are said to be *translucent;* such as ground glass, oiled paper, etc. *Opaque* bodies do not transmit light.

230. A **luminous ray** is a line of light proceeding from a luminous body. A collection of rays is called a *pencil*. Rays are *diver-*

* "The justification of a theory consists in its exclusive competence to account for phenomena. On such a basis the *Wave Theory*, or the *Undulatory Theory* of light, now rests, and every day's experience only makes its foundations more secure."—*Tyndall.*

gent when they separate from one another, and *convergent* when they tend toward the same point. Rays that neither diverge nor converge are *parallel.*

231. Every luminous body emits rectilinear divergent rays from all its points and in every direction.

232. A **medium** is any substance traversed by light, as air, water, glass, etc. When its density and chemical composition are the same in all its parts, it is said to be *homogeneous.*

233. In every homogeneous medium the rays of light are propagated in straight lines.

This becomes obvious when light passes into a dark room through a small aperture, the luminous trace becoming visible by the light falling upon the particles of dust.*

234. A **shadow** is the space from which the light proceeding from a luminous body is excluded by the intervention of an opaque body. The form and extent of this space must depend upon the relative magnitudes, the shapes, and positions of the luminous and opaque bodies.

Let the light be conceived to emanate from a luminous point, S (Fig. 138), M being an opaque spherical body. Straight lines drawn from the point S so as to

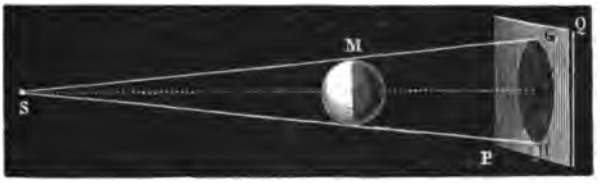


Fig. 138.

touch the surface of M, will indicate the limits of the obscuration, and the form of the shadow, which in this case is a truncated cone, a section of which is seen on the screen P Q as a circular shadow, H G.

But suppose the luminous body, as well as the opaque body, is a sphere, as shown in Fig. 139. Then the lines S M G, L N H indicate the limits of the shadow,

* "Light, though the cause of vision, is itself invisible. A sunbeam, indeed, is said to be seen when it traverses a dark room through a hole in the shutter, or when, in a partially clouded sky, luminous bands or rays are observed as if darted through openings in the clouds, diverging from the place (unseen) of the sun, as the vanishing point of their parallel lines seen in perspective. But the thing seen in such cases is not the light, but the innumerable particles of floating dust or smoky vapor which catch and reflect a small portion of it."—*Sir John Herschel.*

or space of total obscuration; and the lines L M D, S N C, the limits of partial obscuration, called the *penumbra*, a section of which appears on the screen as a partly darkened ring around the circular shadow.

If the luminous body were larger than the opaque body, the shadow would, obviously, be a cone. Thus if M N were the luminous body, and S L the opaque

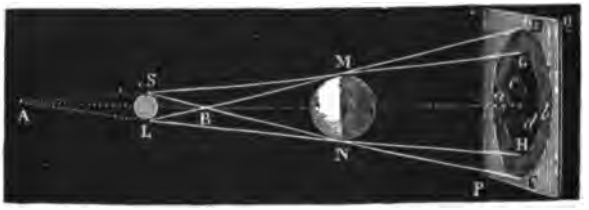


Fig. 139.

body, the space A S L would be the shadow. Such a shadow is always formed behind the earth and moon by their interception of the sun's rays, giving rise to the phenomena of eclipses.

235. **Velocity of Light.**—Light moves with so great a velocity that there is no appreciable interval between any luminous phenomenon and its perception by the eye, except at an immense distance. It requires about 8¼ minutes to pass from the sun to the earth.*

Roemer, a Danish astronomer, first determined this fact by observing that the eclipses of Jupiter's satellites take place earlier when the earth is at the



Fig. 140.

point of its orbit nearest to Jupiter than when at the opposite point, having to cross the orbit, from T to T' (Fig. 140). The retardation was observed to be 16m. 36s., which shows the velocity of light to be somewhat more than 186,000 miles a second. To pass to the earth from the nearest of the stars, light requires about 3¼ years.

* "Considering the enormous velocity of light, the particles, if any exist, must be inconceivably small; for if of any conceivable weight, they would infallibly destroy so delicate an organ as the eye. A bit of ordinary matter one grain in weight, and moving with the velocity of light, would possess the momentum of a cannon-ball 150 pounds' weight, moving with a velocity of 1,000 feet a second."—*Tyndall.*

Methods for determining experimentally the velocity of light have been devised; that of Foucault was a revolving mirror, and that of Fizeau a rapidly rotating toothed wheel. Their determinations of the velocity do not differ materially from that given above.

236. **Intensity of Light.**—The intensity of illumination on a given surface is inversely as the square of the distance from the source of light.

The light emitted by L (Fig. 141) and falling upon the screen C D would produce only *one-fourth* the illumination in falling upon A B at *twice* the distance;

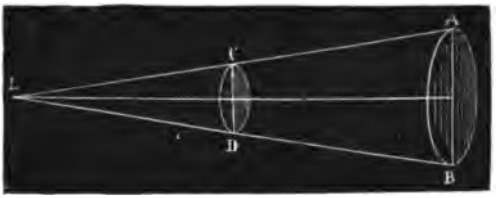


Fig. 141.

because the line A B must be twice C D, and surfaces are as the squares of their corresponding dimensions; therefore the same quantity of light is diffused over a surface four times as great.

237. A **photometer** is an apparatus for measuring the relative intensity of light from different sources.

It is made in various forms. Rumford's photometer consists of a ground glass screen, in front of which is fixed an opaque rod (Fig. 142). The lights to

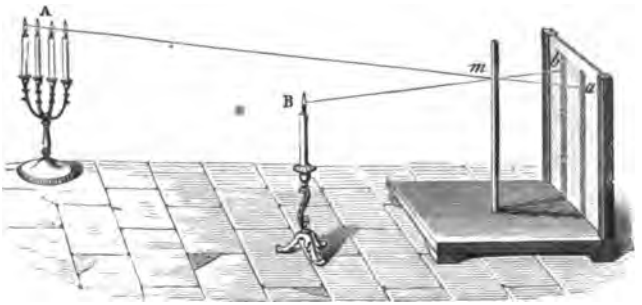


Fig. 142.

be compared—for instance, that of several candles and a single candle—are placed so that each casts a shadow of equal intensity on the screen. Since the shadow caused by the greater light is illuminated by the candle, and that thrown by the

candle is illuminated by the other light, the illumination of the screen due to each is the same. The intensity of the two lights must, then, be proportional to the squares of their distances from the shadows; that is, if the light at A is twice the distance of the candle B, its illuminating power is four times as great.

II.—REFLECTION OF LIGHT. MIRRORS.

238. A luminous ray falling upon a polished surface is reflected from it in the same plane, and so that the angle of reflection is equal to the angle of incidence.

This may be illustrated and proved by the apparatus shown in Fig. 143, which consists of a graduated circle in a vertical plane. Two brass slides move round the circumference, on one of which there is a piece of ground glass, P, and on the other an opaque screen, N, in the center of which is a small aperture. Fixed to the latter slide there is also a mirror, M, which can be more or less inclined while it remains always in a plane perpendicular to that of the graduated circle. There is also a small mirror, *m*, placed horizontally in the center of the circle. The solar ray S falling on the mirror M is reflected through the aperture in N on the center of the mirror *m*, and thence in the direction *m* P, the glass P being moved until the image of the aperture is seen in its center. The number of degrees in the arc A P will be then found to be equal to those in A V; and the reflected and widest rays are obviously in the same plane.

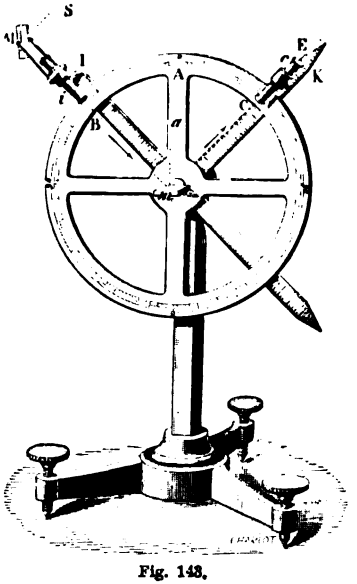


Fig. 143.

That part of optics which treats of the reflection of light is called *catoptrics*.

239. **Mirrors** are bodies with polished surfaces, which show by reflection objects presented to them. Mirrors are, according to their surface, *plane*, *concave*, or *convex*.

240. In **plane mirrors**, the reflected ray seems to come from a point behind the mirror, at a perpendicular distance from it equal to that of the source of the ray in front of it. Hence, the image of any object is seen in the direction of the reflected ray, and as far behind the mirror as the object is in front of it. This image being only apparent, is called a *virtual image*.

Thus every ray from the point A (Fig. 144) falling upon the mirror M N, and reflected as at B, seems to come from the point a, behind the mirror, which can be shown to be as far from the mirror as A; since the lines A N and a N are equal, as can be demonstrated by geometrical proof.

It is obvious that the image of any object is formed by the reflection of the

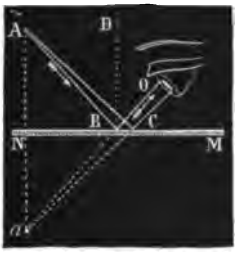


Fig. 144.

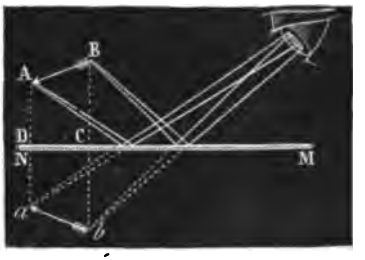


Fig. 145.

rays from each of its points, as shown in Fig. 145, A B being the object and a b the image. In plane mirrors the image is exactly equal to the object, and is symmetrical, and not inverted.

241. **Multiple images** are formed when the mirror has more than one reflecting surface. This is seen when the image of a lighted candle is looked at obliquely in a looking-glass, and is caused by the double reflecting surface of the glass. Metallic mirrors, having only one reflecting surface, can give only one image.

Thus, when the rays from the point A (Fig. 146) meet the surface of the looking-glass M N a part is reflected at b, forming an image, a; but the other part penetrates the glass and is reflected from the metal surface at c, causing another image, a', the distance of which from a is equal to twice the thickness of the glass. The cross reflections of the surfaces give rise also to other faint images. Metallic mirrors are, for this reason, preferable in optical experiments.

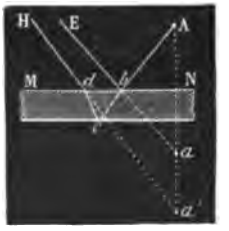


Fig. 146.

When an object is placed between two plane mirrors, forming an angle with each other, a variety of images are formed by the reflections from one mirror to the other, the number depending on the angle of inclination. If this is a right angle, three images are seen; if of 60°, five; and if of 45°, seven, the number increasing as the inclination decreases; so that when the mirrors are parallel, the number is, theoretically, infinite.

242. The **kaleidoscope** is an application of the principle of multiple images caused by inclined mirrors. It was invented by Sir David Brewster.

It consists of a tube in which are three plane mirrors having an inclination to each other of 60°; one end of the tube is closed by a piece of ground glass, and the other by a cap containing an aperture. Between the ground glass and another glass disc, small pieces of colored glass are inserted, which assume different positions as the instrument is turned; and the images of these, as reflected by the mirrors, present an endless variety of symmetrical and beautiful forms.

243. **Regular and Irregular Reflection.**—The light which falls on an opaque body is partly absorbed, and partly reflected—either *regularly*, as by polished surfaces, or *irregularly*, that is, scattered in all directions. The latter, called *diffused light*, is that which renders objects visible; *regular* or *speculoid reflection* renders the reflecting object invisible.

The more complete the reflection of a mirror, the less visible is the mirror itself; but diffused light shows us the objects from which it is reflected. The air diffuses the light of the sun; otherwise the sun would appear as a luminous globe in a dark sky. Twilight is caused by this irregular reflection of the light by the atmosphere, when the sun is a short distance below the horizon.

244. The **intensity of reflected light** is always less than that of the incident light, because some of the original vibrations are converted into vibrations of the reflecting surface. It increases with the obliquity of the incident rays.

On this account, a sheet of white paper will reflect the image of a light when viewed obliquely, but not when viewed perpendicularly.

The intensity of reflected light varies with different bodies. When the incident rays are perpendicular, a metal mirror reflects $\frac{3}{4}$ of the light; a looking-glass coated with mercury, $\frac{1}{2}$; surface of glass, $\frac{1}{18}$; and that of water, $\frac{1}{50}$.

245. The **heliograph** is an apparatus for signaling at great distances by means of reflected solar light.

It consists simply of a small mirror mounted, and so adjusted that it can receive the light of the sun and reflect it to any particular point. By varying the motions and changing the reflections, or obscuring them for a longer or shorter time, alphabetic signals can be produced. The heliograph was used by the English with good effect in some of their recent wars, as in Afghanistan and Africa. Signals have been sent at the rate of twelve words a minute a distance of 40 miles.

246. **Curved Mirrors.**—When a concave or convex mirror has a curvature corresponding to the inner or outer surface of a sphere, it is sometimes called a *spherical mirror*. There are other forms of curved mirrors, such as the *parabolic mirror*, the curvature of which corresponds to that of the curve called a parabola.

247. The **focus** of a curved mirror is the point in which the re-

flected rays meet, or tend to meet, if produced backward or forward. There may be either a *real focus*, or a *virtual focus*.

The angle formed by joining the extremities of a spherical mirror with the center of curvature is called its *aperture*. The aperture is usually quite small—from 8 to 10 degrees—in order to avoid certain irregularities in the reflections, to be referred to farther on.

248. **Concave Mirrors.**—Parallel rays falling upon a concave (spherical) mirror are reflected to a point called the *principal focus*, which is very nearly half-way between the surface of the mirror and the center of curvature.

Parallel rays are those that are parallel to the *principal axis*, A L (Fig. 147), of the mirror. These, by the general law as to the equality of the angles of in-



Fig. 147.

cidence and reflection (C B H, C B F, etc.), are reflected to F, which is very nearly half-way between A and C. Perfectly parallel rays presuppose that the luminous source is at an infinite distance; but the sun is so far distant that the solar rays may, practically, be considered parallel. In these cases, it will be seen that the normal or perpendicular from which the angles of incidence and reflection are determined, is the line drawn from the center C to the surface of the curved mirror.

Conversely, if a luminous body be placed at F, the principal focus, the reflected rays will be parallel.

249. **Divergent rays** falling from a luminous point upon a concave mirror are reflected to a *real focus* in front of the mirror, or form a *virtual focus* behind it, according as the luminous point is beyond the principal focus, or between it and the mirror.

Let us conceive the luminous point to be at L (Fig. 148), beyond the center of curvature. It will be obvious that as the angle of incidence C K L is less than C K S, the angle formed by an incident parallel ray, the angle of reflection must be less, which will bring the focus to some point, as *l*, beyond the principal focus F. This point *l* is called the *conjugate focus*.

If the luminary were at *l*, it is obvious that the conjugate focus would be at L; hence L and *l* are called the *conjugate foci*; if it were at C, the incident and

reflected rays would coincide with C K, the normal or perpendicular; if at F, there would be no conjugate focus, as the reflected rays would be parallel.



Fig. 148.

But when the luminous point is placed between the principal focus and the mirror, as at L (Fig. 149), in order that the angle of reflection C M E may be equal to the angle of incidence C M L, the reflected rays must diverge, appearing to converge to a point, *l*, behind the mirror. This is called the *virtual focus.*

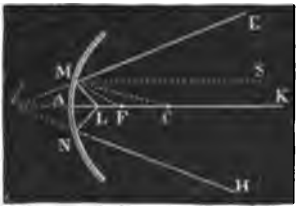


Fig. 149.

When the luminous point is not on the principal axis, another axis must be formed by drawing a line from it to the mirror passing through the center of curvature. This is called the *secondary axis.* The same reasoning, of course, determines the other points in relation to it, as that applied to the principal axis.

To find the center of curvature of a concave mirror, a simple method is, to expose it to the sun's rays, and hold it at such a distance from a screen that an intensely brilliant point of light may be formed. This will be the principal focus; and at about twice that distance will be the center of curvature.

250. The **image formed by a concave mirror** is either inverted and smaller than the object, or erect and larger, depending upon the

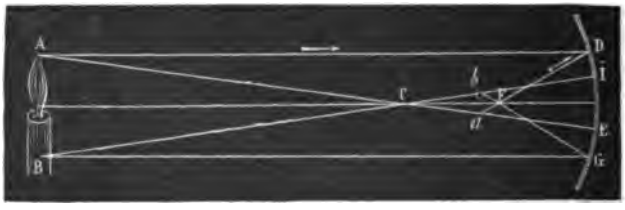


Fig. 150.

distance of the object from the mirror. In the former case, it is a *real image,* in the latter, a *virtual image.*

The preceding explanation of principles will render this intelligible. As

every point of the object reflects the rays of light, it may be considered a luminous point; and the light it emits is reflected according to those principles. Thus let the object be A B (Fig. 150). This being situated beyond the center C, the rays are reflected to points between the principal focus and the center, where an actual image of the object is formed. To show that it is smaller and inverted, take the point A, and find the secondary axis A E; and the conjugate focus *a* will be on the line, where the reflected rays cross it. In the same manner, the conjugate focus of B will be at *b*; and these being the extreme points of the image must indicate its limits. As the reflected rays cross each other, the image is inverted.

The nearer the object is to the center of curvature, the less is the difference in size between the object and image; and when the object is at the center, the image is equal to it. When the object is at the principal focus, no image is formed, as the reflected rays are parallel.

Virtual Image.—When the object is placed between the principal focus and the mirror, a virtual image is formed behind the mirror, which is erect and larger than the object. Let A B (Fig. 151) be the object. The incident rays from A are reflected in various directions as D I and K H, and intersect each other at a point, *a*, behind the mirror, on the secondary axis, C A, prolonged, where they form a virtual image. In the same manner an image, *b*, of B is formed; and thus the eye sees the image of A B, which is erect, because the rays do not cross, and is larger than the object, because it is seen under a larger angle.

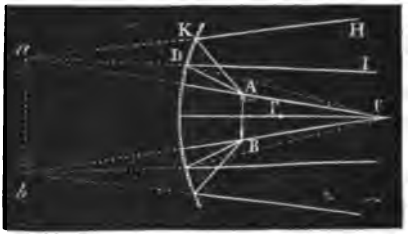


Fig. 151.

Thus, when a person stands at a certain distance from a concave mirror, he sees an actual image of himself inverted and smaller; at a less distance the image becomes confused, and when he is at the focus, disappears; but as he approaches still nearer, the image appears erect, but larger; the latter is a virtual image.

Many curious and sometimes startling effects may be produced by concave mirrors. For example, let an inverted bouquet be suspended in a box open at one side, and let the box be placed in front of a concave mirror at a distance about equal to its radius of curvature, with the open side toward the mirror. Then, by giving a proper inclination to the mirror, a phantom image of the bouquet will appear in mid-air, just above the top of the box, provided the spectator stand so that all parts of the image lie between his eyes and the mirror.

251. **Convex Mirrors.**—Parallel rays falling upon a convex mirror diverge from the surface of the mirror, appearing to meet at the principal focus, behind the mirror, which like that of a concave mirror, is very nearly at the center of the radius of curvature.

Let S I, T K, B A, S′ E (Fig. 152), be rays parallel to the principal axis of a convex mirror. These, after reflection, take the diverging directions, I M, K H,

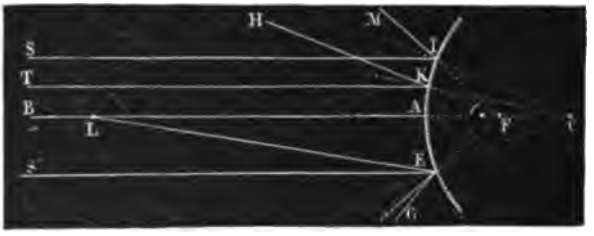


Fig. 152.

E G, and when continued, meet in a point, F, about the middle of A C, C being the center of curvature. If the incident luminous rays, instead of being parallel to the axis, proceed from a point, as L, a virtual focus will be formed at a point, *l*, between the principal focus and the mirror.

252. **The image formed by a convex mirror,** whatever the position of the object, is always virtual, erect, and smaller than the object.

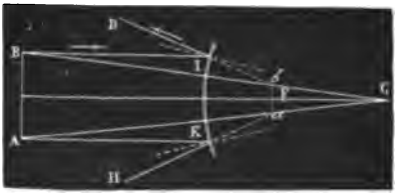


Fig. 153.

Let A B (Fig. 153) be an object placed before a convex mirror at any given distance. A C and B C are secondary axes, upon which, respectively, all the divergent rays from A and B are collected at the points *a* and *b*, between which points is seen a virtual image of the object, which must, obviously, be smaller than the object and erect.

253. **Spherical Aberration.**—When the angular aperture of a spherical mirror does not exceed 8 or 10 degrees, the reflected rays pass through only one point; but when the aperture is larger, the rays reflected near the edges meet the axis nearer the mirror than those reflected by the part near the center. This causes a want of definition or clearness in the image, called *spherical aberration.*



Fig. 154.

254. **Caustics.**—Every reflected ray cuts the one next to it, and their points of intersection form in space a curved surface, called the *caustic by reflection.*

The curve F M (Fig. 154) represents one of the branches of a section of this surface made by the plane of the paper. When the light of a candle is reflected from the inside of a cup or tumbler, a section of the caustic surface can be seen by partly filling the cup or tumbler with milk. To show the form of the caustic curve, place edgewise on a sheet of white paper a strip of polished metal bent into the form of a circular arc, and let a light fall on its concave surface, which will be reflected on the paper so as to exhibit the caustic.

255. **Parabolic mirrors** are concave mirrors having the form of the curve known as the parabola.

A parabolic mirror may be conceived as generated by the revolution of the arc of a parabola, A M (Fig. 155), about its axis, A X. It is a property of the parabola that the straight line F M, drawn from the focus F to any point, as M, of the curve, and the line M L, parallel to the axis A X, make equal angles with the tangent T T′ at that point. Hence, all rays parallel to the axis after reflection meet in the focus F of the mirror; and, conversely, when a light is placed in the focus, the rays that fall on the mirror are reflected parallel to the axis. Parabolic mirrors are, therefore, free from the defect of spherical mirrors, which is, that parallel rays do not converge exactly at the principal focus. They are used in carriage lamps and the lamps of locomotives.

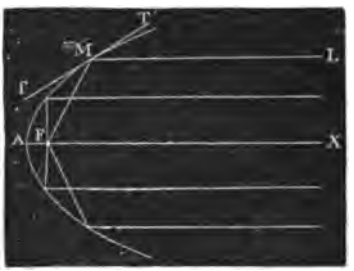


Fig. 155.

256. **Cylindrical and conical mirrors** present images distorted in a ludicrous manner, varying according to the position of the axis.

By an application of the laws of reflection, the exact form of the distorted figure may be geometrically constructed. Thus, by inversion, an apparently uncouth, hideous, or almost shapeless object may be presented to a cylindrical or conical mirror, and the reflected image be a beautifully symmetrical form. This is called *anamorphosis*.

257. Concave mirrors are very often used to concentrate light upon an object so as to render it more clearly visible.

Such is the *ophthalmoscope*, a small concave mirror with a small aperture in the center, through which the oculist looks from behind, while he reflects a beam of light into the pupil of his patient's eye, thus rendering the retina sufficiently visible to be examined.

The *laryngoscope* consists of a small plane mirror with a handle so arranged at an angle as to be held at the back of the patient's mouth, into which the light is thrown by a concave mirror attached to the observer's forehead. Instead of a concave mirror, a convex lens is sometimes used for the purpose of illumination; and instead of solar light, that of a lamp provided with a concave reflector.

III.—REFRACTION OF LIGHT. LENSES.

258. **Refraction** is the deflection, or bending, which luminous rays experience in passing obliquely from one medium into another, as from air into water or glass. When the incident ray is perpendicular to the surface of the medium, it undergoes no refraction.* That part of optics which treats of refraction is called *dioptrics*.

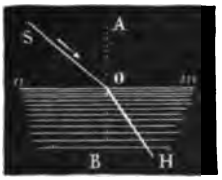


Fig. 156.

Let S O (Fig. 156) represent an incident ray falling obliquely on the surface, *m n*, of water; the refracted ray may then be represented by O H, which makes a smaller angle with the perpendicular A B, than the incident ray S O. The angle S O A is called the *angle of incidence*, and B O H, the *angle of refraction*.

The direction of the refracted ray, or the amount of refraction, depends on the relative velocity of light in the two media, the most highly refracting medium, according to the undulatory theory, being that in which the velocity is least.

Certain crystallized bodies, such as Iceland spar, break the incident ray into two refracted rays. This is called *double refraction*. (Art. 302.)

259. **Laws of Refraction.**—1. When the rays of light pass into a denser medium, as from air into water, they are bent toward the perpendicular. (See Fig. 156.) 2. When they pass into a rarer medium, as from water into air, they are bent from the perpendicular. 3. The incident and refracted rays are in the same plane, which is perpendicular to the common surface of the two media.

The angles of incidence and refraction are thus unequal, the latter being greater or less than the former, according to the relative density of the refracting medium. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is called the *index of refraction*.† It varies with the medium,

* "To account for refraction, let us for the sake of simplicity take a portion of a circular wave emitted by the sun or some other distant body. A short portion of such a wave would be straight. Suppose it to impinge from air upon a plate of glass, the wave being in the first instance parallel to the surface of the glass. Such a wave would go through the glass without change of direction. But as the velocity in glass is less than the velocity in air, the wave would be retarded on passing into the denser medium. But suppose the wave, before impact, to be oblique to the surface of the glass; that end of the wave which first reaches the glass will be first retarded, the other portions being held back in succession. This retardation of one end of the wave causes it to swing round; so that when the wave has fully entered the glass, its course is oblique to its first direction. It is *refracted*."—*Tyndall.*

† The sine of an arc, or the angle measured by it, is a perpendicular drawn from one extremity of the arc upon a radius passing through the other extremity. It is thus a rectilinear measure of the angle.

and is, in fact, the ratio of the velocity of the incident rays to that of the refracted rays, being, for example, from air to water, approximately, $\frac{4}{3}$; from air to glass, $\frac{3}{2}$. From water to air it is, of course, reversed, $\frac{3}{4}$; and from glass to air, $\frac{2}{3}$.

The *absolute index of refraction* of any medium is the refractive index when the rays pass into the medium from a vacuum; and the *relative index*, when the light passes from one medium into another, is the ratio of the absolute index of the one to that of the other. The following shows, approximately, the absolute index of a few substances:

Pure water	1.33	Crown-glass	1.53
Alcohol	1.37	Flint-glass	1.61
Humors of the eye	1.38 to 1.34	Sapphire	1.79
Oil of turpentine	1.48	Diamond	2.47 to 2.75

Phenomena of Refraction.—There are many interesting phenomena due to refraction. Bodies immersed in water appear nearer the surface than they really are. Thus an object at L (Fig. 157) seen in water appears at L', because the rays passing from it are refracted, as at A and B, taking the directions A C and B D, which intersect at L', where the body seems to be, as it is seen in the direction in which the ray strikes the eye.

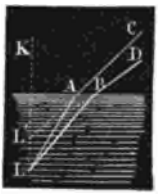


Fig. 157.



Fig. 158.

For a similar reason a stick plunged obliquely into water appears bent, the immersed part being raised (Fig. 158). The following familiar experiment will illustrate this effect of refraction: Place a coin in a basin, and stand in such a position that looking obliquely over the top of the basin, the coin may be just out of sight. Now pour water into the basin, and the coin will become visible.

As the rays of light from the heavenly bodies are refracted in passing through

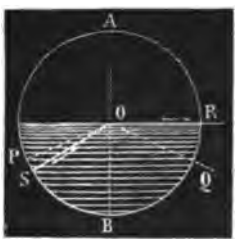


Fig 159.

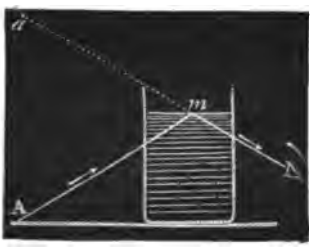


Fig. 160.

the atmosphere, these bodies are not seen in their true places except when in the zenith. This gives rise to *astronomical refraction*, which increases the altitude of the heavenly bodies—at the horizon, about half a degree.

260. **Total reflection** is a phenomenon produced when the

incident ray does not emerge from the refracting medium, but undergoes an internal reflection.

Let the incident ray be S O (Fig. 159), passing from a dense medium into a rare one; and the angle of incidence S O B, be such that the angle of reflection A O R may be a right angle, and the refracted ray O R be coincident with the surface of the medium. Now, if the angle of incidence be greater than S O B, as P O B, it will follow that the angle of refraction will be greater, as A O Q; and thus the refracted ray O Q does not emerge, but is reflected. The angle S O B is called the *critical angle* (or *limiting angle*). From water to air it is 48° 35′; from glass to air, 41° 48′ (flint-glass, 38° 41′); from the diamond to air, 23° 42′.*

The following experiment will illustrate this: Place an object, A (Fig. 160), in a certain position before a glass vessel filled with water; so that when the surface is looked at, as shown in the figure, the object may be seen at *a*, the rays being reflected at *m*, after refraction, in the direction of *m a*.

Similar effects of total reflection, as seen in aquaria, add much to the beauty of their appearance.

As in total reflection there is no loss of light from absorption or transmission, the effects are of extreme brilliancy. The luster of transparent bodies having plane surfaces, as the facets of glass chandeliers, and especially of those of the diamond, is due to total reflection.

261. The **mirage** is an optical illusion causing inverted, and

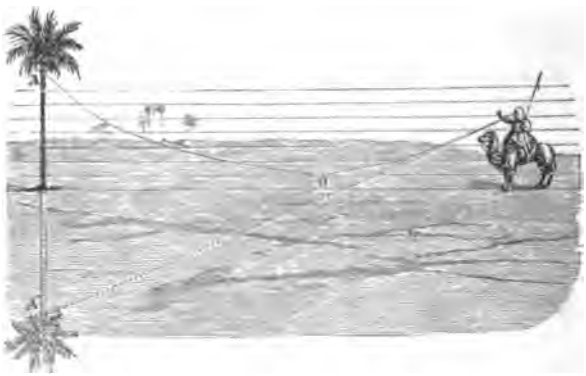


Fig. 161.

sometimes double, images of distant objects to be seen in the atmosphere or below the ground.

This phenomenon is of most frequent occurrence in hot climates, especially

* "Realize clearly that a bundle of light rays filling an angular space of 90° before they enter water, are squeezed into an angular space of 48° 27′ within the water, and that in the case of the diamond the condensation is from 90° to 23° 42′."—*Tyndall.*

on sandy plains, where the ground often presents the aspect of a tranquil lake, on which are reflected trees and villages. It is caused by the refraction resulting from the unequal density of the different layers of the air when expanded by contact with the heated soil. The least dense of these are then the lowest, and a luminous ray from an elevated object, as A (Fig. 161), passes through layers which are less and less refracting, since the less the density the less the refracting power of a substance. When the direction incidence reaches the critical angle, the ray rises, as seen in the figure, and undergoes a series of refractions in the direction contrary to the first, since it passes through layers gradually increasing in density. It then reaches the eye in the direction O A′, as if it proceeded from a point below the ground, giving an inverted image of the object as reflected from the calm surface of a lake.*

The phenomenon called *fata morgana*, observed in the Strait of Messina, is a kind of mirage. A person on the shore at this place sees upon the water images of various objects—looking like castles, towers, villages, trees, sometimes plains with herds of cattle, and armies of horse and foot, all passing along the surface of the sea. Sometimes they are seen in the air, but not so vividly, and occasionally are fringed with colors. They were attributed by the common people to the fairy (Italian, *fata*) Morgana. Hence the name.

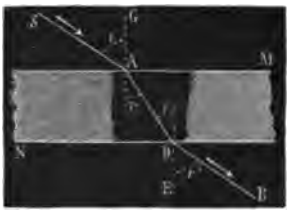


Fig. 162.

262. When light passes through a medium having parallel faces, the emergent rays are parallel to the incident rays.

Let M N (Fig. 162) be a glass plate with parallel faces; and let S A be the incident ray. This ray, being bent toward the perpendicular, passes through the glass in the direction A D; and, it is obvious, that at D it will be bent from the perpendicular as much as it was at A bent toward it, and will emerge in the direction D B, parallel to S A. Thus, objects observed through a window-pane are seen in their true places and with their proper forms, unless the glass is of unequal density, or has an uneven surface.

263. **Refraction by Prisms.**—A prism, in optics, is any transparent medium having two plane refracting surfaces inclined to each other.

The intersection of the two faces is called the *edge* of the prism, and their inclination is the *refracting angle*. The prisms used for experiments are usually right triangular prisms (Fig. 163), a section of which is shown in Fig. 164. The

* "While the French army was marching through the sandy deserts of Lower Egypt, they saw various phenomena of unusual refraction, to which they gave the name of *mirage*. When the surface of the sand was heated by the sun, the land seemed to be terminated at a certain distance by a general inundation. The villages situated upon eminences appeared to be so many islands in the middle of a great lake, and under each village there was an inverted image of it."—*Brewster's Optics*.

point A is called the *summit* of the prism, and the line B C the *base*. The incident ray O D, being refracted at D, passes through the prism in the direction D K,



Fig. 163.

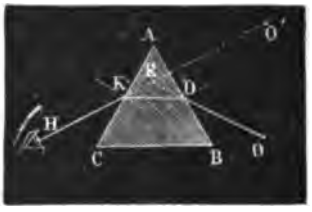


Fig. 164.

nearer the normal, or perpendicular, and at K passes out in the direction K H away from the perpendicular. Thus it is refracted twice in the same direction, toward the base; and the eye sees the object at O', nearer the summit than its true position. The angle O E O' is called the *angle of deviation*; it increases with the index of refraction of the material of the prism, as well as with its refracting angle.

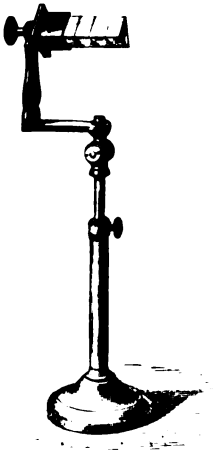


Fig. 165.

The *polyprism* is formed of several prisms having the same angle, connected at their ends (Fig. 165). These prisms are composed of different substances, such as flint-glass, rock-crystal, and crown-glass; and an object seen through them appears at different heights, at the greatest when seen through the flint-glass, as that has the largest index of refraction.

The *right-angled prism* affords a useful application of the principle of total reflection. Let A B C (Fig. 166) be a section of such a prism, O a luminous point, and O H a ray at right angles to the face B C. This ray enters the glass without being refracted, and makes with the face A B an angle of 45°. This angle being greater than the critical angle of glass (41° 48'), the ray undergoes total reflection, which gives to it a direction, H I, perpendicular to the face A C. In this way the hypothenuse face of this prism acts as a perfect plane mirror; and an eye at I sees the image of O at O'. Such a prism has a valuable application in several optical instruments, as the telescope.

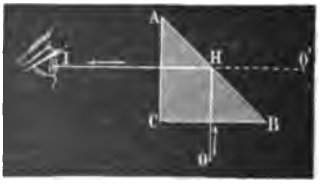


Fig. 166.

264. **Lenses.**—A lens is a transparent body with two surfaces, of which one at least is curved; and is used to cause, by refraction, the rays of light passing through it to converge or diverge.

265. There are six kinds of lenses, classified according to the surfaces by which they are formed; four being formed of curved surfaces, and two of a curved and a plane surface.

These are shown in Fig. 167, where A is a *double convex* lens; B, a *plano-convex;* C, a *converging meniscus*, or *concavo-convex;* D, a *double concave;* E, a

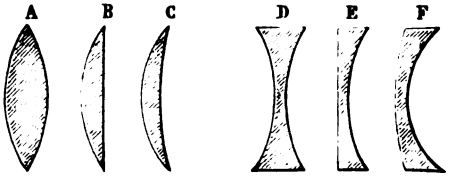


Fig. 167.

plano-concave; F, *concavo-convex*, or *diverging meniscus*. The first three, which are thicker at the center than at the edge, cause the rays to converge; the others cause them to diverge.

The *principal axis* of a lens of two curved surfaces is a straight line drawn through the centers of curvature; of a lens having a plane surface, it is the perpendicular let fall from the center of the spherical face on the plane face.

266. The **focus** of a lens is the point at which the refracted rays, or their prolongations, meet. A double convex lens has a real and virtual focus, like a concave mirror.

267. **Convex Lenses.**—Parallel rays falling upon a convex lens meet, after refraction, at a point called the *principal focus*. Divergent

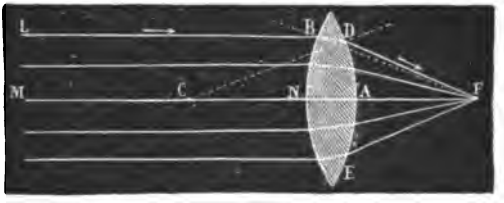


Fig. 168.

rays become parallel, convergent, or divergent, according to the position of the source of light.

Thus the ray L B (Fig. 168), parallel to the principal axis M F, is refracted at B and D, and meets the axis at F, where the other parallel rays meet, when the arc D E does not exceed 10° to 12°. The line F A is called the *focal distance*.

In ordinary lenses, which are of crown-glass,* and in which the radii of the two surfaces are equal, the principal focus F coincides very nearly with the center of curvature.

When the luminous point is at F, the lens converts the divergent into parallel rays; but when the luminous point is beyond F, on the principal axis, as at L (Fig. 169), they are made to converge to a point, *l*, called the *conjugate focus*.

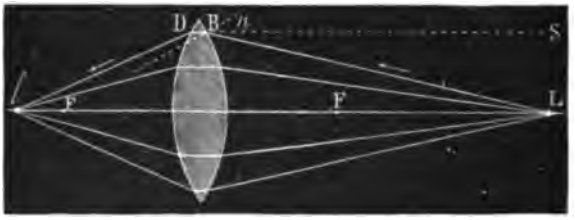


Fig. 169.

According as the luminous point comes nearer the focus F, the convergence of the emerging rays decreases, the focus *l* becoming more distant; when the source of light is at F, the point *l* is infinitely distant, the emerging rays being parallel; and when the light is between the focus F and the lens, the emerging rays diverge, and form a virtual focus, *l* (Fig. 170), the same side of the lens as the luminous point; because the incident rays, as F I, make greater angles with the perpendicular than the ray F I; and, therefore, they emerge at a greater angle, and become divergent rays, as H K, G M.

The *optical center* of a lens is a point on the axis through which the luminous rays pass without undergoing any change of direction, the emergent ray being parallel to the incident ray. In a double-convex or double-concave lens, the sur-

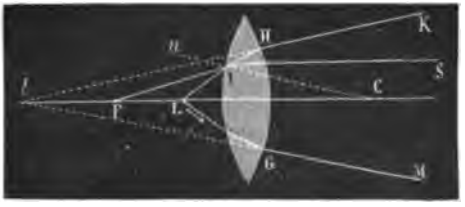


Fig. 170.

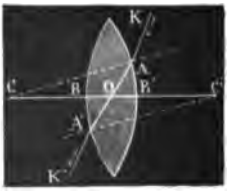


Fig. 171.

faces of which are of equal curvature, this point is midway between the surfaces; in lenses with a plane face, it is at the intersection of the axis with the curved face.

Every straight line which passes through the optical center of a lens is a *secondary axis*.

* Crown-glass is a fine sort of window-glass, not containing the oxide of lead, which is an ingredient of flint-glass, and serves to give the latter its peculiar character.

To find the optical center of a lens, draw any radius, as C A (Fig. 171), from the center of curvature C to any point of the curve, as A; and from the other center of curvature C' draw a parallel radius C' A'; connect these points by the straight line A A', and the point of intersection O with the axis will be the optical center of the lens. For the part of the lens contained between the parallel radii may be considered a medium with parallel faces; and hence the ray K A which enters it at A emerges from it at A' as a parallel ray, A' K'. Every luminous ray that passes through the point O may be considered a secondary axis, since the deviation of the ray from a straight line is very slight in passing through a medium with parallel faces.

268. The **image formed by a convex lens,** like that of a concave mirror, is either real and inverted, or virtual and erect, according to the distance of the object from the lens. When virtual, the image is always magnified. The real image is larger than the object, when the latter is a little beyond the principal focus; and much smaller, when the object is at a distance.

In lenses, as in mirrors, the image of an object is the collection of the foci of its several points. Let A B (Fig. 172) be placed beyond the principal focus of

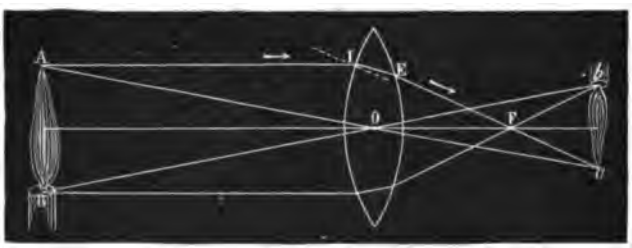


Fig. 172.

the lens whose optical center is O. Every ray from the luminous point A will be refracted at I and E and cross the secondary axis at *a*, the conjugate focus of A. In the same manner, rays from B cross the secondary axis at *b*; and as the points between A and B have their foci between *a* and *b*, a *real* image is formed there, which is inverted because the rays cross, and is smaller because the rays are made to converge. This image may be received on a screen, and thus seen; or the eye may be so placed as to receive it on the retina. It is obvious that if *a b* were the illuminated object, A B would be the image, and in that case would be larger than the object.

When an object, as A B (Fig. 173), is placed between the lens and its principal focus, every ray from the point A, as A C, after being refracted at C and D, diverges from its secondary axis, O A, crossing the prolongation of it at *a* (see Fig. 170); and in the same manner those from B intersect at *b*, between which points a virtual image is formed, larger than the object, because seen under a

larger angle, and erect because the rays do not cross. This makes the double-convex lens a magnifying glass, or *simple microscope*, the magnifying power being

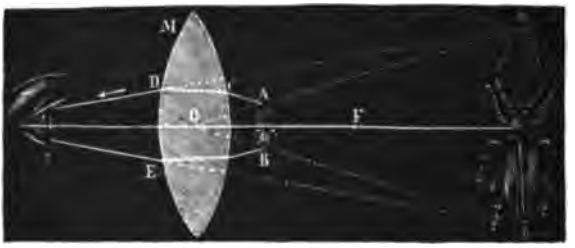


Fig. 173.

greater in proportion as the lens is more convex, and the object nearer the principal focus.

269. **Concave Lenses.**—Luminous rays falling upon a concave lens, whether they are parallel or divergent, diverge after refraction, and meet at a virtual focus on the same side of the lens as the source of light.

Let S S′ (Fig. 174) be any pencil of rays parallel to the axis of the concave lens. The ray S I is refracted at the point of incidence I, and is brought nearer

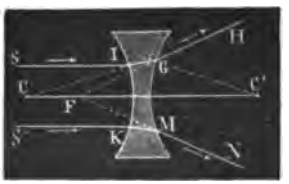


Fig. 174.

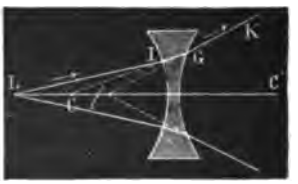


Fig. 175.

to the normal C I; on emerging at G it is refracted from the normal G C′, and becomes G H, so that each refraction removes it from the axis C C′. In the same way the parallel ray S′ K emerges as M N. Hence, as these rays all diverge, there is no real focus, but a virtual focus at their point of intersection, F. This is called the *principal virtual focus*.

When the rays proceed from a luminous point, L (Fig. 175), on the axis, it may be shown by a similar construction, that a virtual focus is formed at *l*, between the principal focus and the lens.

270. The **image formed by a concave lens,** like that of a convex mirror, is always a virtual one, erect and smaller than the object.

Let A B (Fig. 176) be an object placed in front of a double-concave lens, the

optical center of which is O. If the secondary axis A O be drawn from the point A, all rays, A C, A I, from this point are twice refracted in the same direction, divergent from the axis A O; so that the emerging rays, D E and G H, appear to come to the eye from *a*, the point where their prolongations cross the secondary axis. In like manner the rays from B cross the secondary axis B O at *b*; and between *a* and *b* an image, *a b*, is formed.

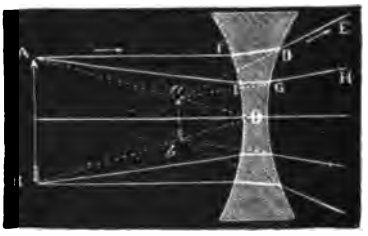


Fig. 176.

Spherical aberration causes an indistinctness in the images formed by lenses of large aperture, as in the case of mirrors (Art. 253). The rays emitted by a single point do not, as has been conceived, intersect at a single point when the aperture of the lens exceeds 10° or 12°. In that case, the rays which traverse the lens near the edge are refracted to a point, F (Fig. 177), nearer the lens than

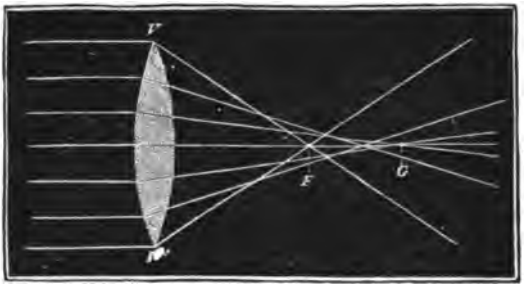


Fig. 177.

the point G, which is the focus of the rays which pass near the axis. This is called *spherical aberration by refraction.*

Caustics by refraction are the luminous surfaces formed by the intersection of the refracted rays. (Art. 254.)

IV.—COMPOSITION OF LIGHT. COLORS.

271. White light is found by means of refraction to be composed of several different kinds of light, each of a peculiar color.

To decompose a pencil of light, as S A (Fig. 178), let it pass through a small aperture into a dark chamber, placing a flint-glass prism, P, horizontally in its path. The beam on emerging will then be refracted toward its base, and will fall on a screen in the form of a vertical band rounded at the ends and showing all the colors of the rainbow.

272. **Solar Spectrum.**—This band of colors is called the *solar spectrum*, being formed of the light of the sun. It contains the *seven principal colors*—violet, indigo, blue, green, yellow, orange, red, and all their intermediate tints. This separation of light into its component rays is sometimes called *dispersion.**

This separation takes place on refraction, because the rays are not equally refrangible, some being bent more than others. The position of the colors in the spectrum shows that the violet rays are the most refrangible and the red the least (see Fig. 178). Violet occupies the greatest space in the spectrum, and

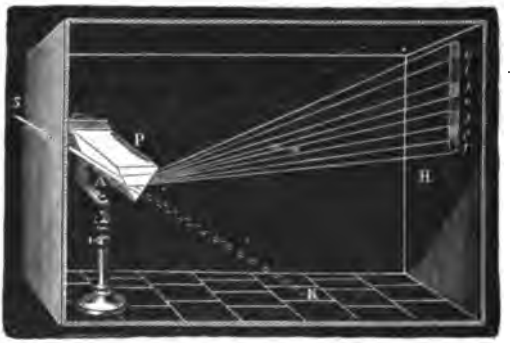


Fig. 178.

orange the least. The length of the spectrum varies with the *dispersive power* of the substance composing the prism. The dispersive power of flint-glass is almost double that of crown-glass.

The color of light depends on the length of the ether waves, which gradually diminish from the red to the violet. The length of a wave of red light has been estimated to be about .000024 of an inch; that of a wave of violet light, about .000016 of an inch. These are the extremes. The velocity of light being 186,000 miles in a second, this reduced to inches and divided by .000024 will give the number of waves of red light that must enter the eye in a second—equal to more than 490 billions; while those of violet light are more than 700 billions.

Color is to light what pitch is to sound; since the pitch of a note depends on the number of air-waves that strike the ear in a second, and the color of the light, upon the number of ether waves which strike the eye in a second.

273. The spectrum formed by an artificial light contains one or

* Sir Isaac Newton was the first to unravel the solar light, and thus to show that it is composed of an infinite number of rays of different degrees of refrangibility. This is accounted for by conceiving the waves of ether which are generated by luminous bodies to be of unequal length. In the process of refraction, the short waves, being more retarded than the long ones, are bent farther from their direct course.

more of the colors of the solar spectrum, arranged in the same order. The color of the flame is the predominating color of the spectrum.

274. The colors of the spectrum are simple and cannot be further decomposed by refraction.

This can be shown in the following manner: By means of a screen, E (Fig. 179), intercept all the colored rays of the spectrum except one, and let that pass



Fig. 179.

through a second prism, B; and it will be found that, though the rays are refracted, the image received on the screen H is of the same color as the rays allowed to pass, showing that no further decomposition can be effected.

275. The **recomposition of white light** may be effected by allowing the refracted rays to pass through a second prism of the



Fig. 180.

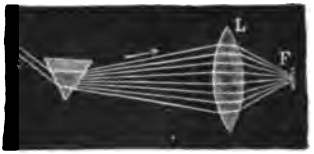


Fig. 181.

same material and same refracting angle as the first, but inverted in position.

This is shown in Fig. 180. The pencil of light S dispersed by one prism is recomposed by a second, passing beyond the latter as a pencil of white light, and parallel to S.

Instead of a second prism, a double-convex lens may be employed, as shown in Fig. 181.

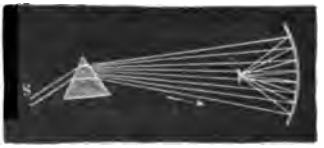


Fig. 182.

When the spectrum is made to fall upon a concave mirror, as shown in Fig. 182, a white image is formed in the focus, the dispersed rays being recombined by the mirror.

That the seven colors of the spectrum form white can be shown by an apparatus called *Newton's disc* (Fig. 183). This is a circular piece of cardboard about a foot in diameter, the center and edges of which are covered with black paper, while in the space between these are pasted strips of paper of the colors of the spectrum, in their proper proportions (Fig. 184). When this disc is rapidly



Fig. 184.

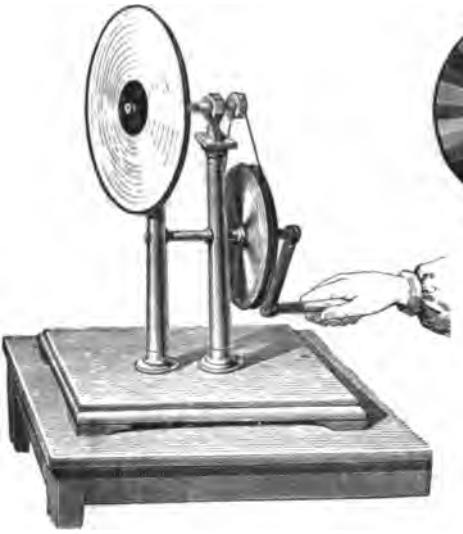


Fig. 183.

rotated, the impressions of the colors are blended, and the effect on the retina is nearly the same as that of white light.* It is not exactly the same, because the proportions of color cannot be made precisely to correspond with those of the spectrum, the intermediate hues being absent; and, moreover, the pigments cannot be perfectly pure.

276. **The color of bodies** depends upon the portion of white light which they reflect to the eye.

Bodies partly absorb and partly reflect the light which falls on their surface. Those which reflect all the colors in the proportion in which they exist in the spectrum are white; those which absorb all, reflecting none, are black. If a body appears red, it shows that it reflects the red rays and absorbs all the others. Colors are reflected from bodies in an almost infinite number of combinations, giving rise to the varied hues which they present. It is obvious from this that bodies have no color of their own.

* This depends on the physiological fact that sensation always lasts a little longer than the impression producing it. If, therefore, a new impression takes place before the previous sensation has ceased, the sensations are blended.

277. **Complementary colors** are any two colors which, when compounded, produce white. Thus, of the colors of the spectrum, *red* and *greenish yellow* are complementary; also *orange* and *Prussian blue*, or *yellow* and *indigo blue*, or *violet* and *greenish yellow*.

If any colors be removed from the spectrum (see Fig. 179), the color formed by a composition of these, blended with that composed of the remaining colors of the spectrum will produce white. From a mixture of red, green, and violet, all possible colors may be produced; hence these three colors of the spectrum are called the *fundamental colors*.

Mixtures of *spectral colors* and *pigment colors* do not yield the same result. When blue and yellow of the spectrum are mixed, the resulting color is white; but pigment yellow and blue produce green; because the blue paint absorbs the yellow, orange, and red; and the yellow absorbs the blue, indigo, and violet, so that only the green is reflected.

278. **Chemical and Heat Rays.**—The rays of the solar spectrum are of three kinds: *Colorific*, or luminous rays; *calorific*, or heat rays; and *actinic*, or chemical rays.

A thermometer will show that the temperature increases from the violet to the red, becoming most intense in the dark space beyond the red. The chemical action may be observed by noticing its action on the chloride of silver, which becomes black under the influence of light. This effect will be found to be least at the red, and greatest at the violet, extending into the dark space beyond. Thus it will be seen that, besides the visible rays, there are invisible heat and chemical rays. The latter are called actinic rays. Artificial lights contain the three kinds of rays in different proportions.*

The growth of plants illustrates the chemical action of light; since it is under the influence of the sun's rays that the carbonic acid in the atmosphere is decomposed, and the plant assimilates the carbon, while the oxygen is set free.

279. **Fraunhofer's Lines.**—When the solar spectrum is carefully observed, it is found to be crossed by a great number of very delicate dark lines at unequal intervals.

These lines attracted the attention of Dr. Wollaston in 1802, but they were first minutely described and mapped by Fraunhofer, an optician of Munich, after whom they were named. They were designated by him as shown in Plate I., Fig. 11. A and B are seen in the red, C at the boundary of the red and orange, D in the yellow, E in the green, F in the blue, G in the indigo, and

* "In the case of the electric light, the energy of the non-luminous, calorific rays emitted by the carbon points is about eight times that of all the other rays taken together. The dark calorific rays of the sun also, probably, exceed many times in power the luminous solar rays. It is possible to sift the solar or the electric beam so as to intercept the luminous rays, while the non-luminous rays are allowed free transmission."—*Tyndall.*

H in the violet. Other lines, as *a* and *b*, are also seen. Fraunhofer counted over 600 of these lines; Brewster, 2,000. The existence of at least 3,000 has been ascertained.

In the solar spectrum, the positions of these lines are always the same; hence, Fraunhofer called them the *Fixed Lines*. In the spectra of the stars and of artificial lights, the lines have different positions. In the spectrum of the electric light, there are brilliant instead of dark lines; as there are also in the spectra of flames in which chemical substances are burning.

280. There are three kinds of spectra: the *continuous spectrum*, produced by the light of incandescent solids and liquids (as iron white-hot); the *line spectrum*, consisting of a number of bright lines, produced by ignited gases and vapors; and the *absorption spectrum*, like that of the sun and stars. The latter is always seen when the light of an incandescent solid or liquid is made to pass through that of a burning gas.

In Plate I., the continuous spectrum is seen in Fig. 1. The spectrum of burning sodium (Fig. 2) has a bright yellow band in exactly the same place as Fraunhofer's dark line, D; while the other colors are wanting. The spectrum of lithium (Fig. 3) is marked by a line in the red and one in the orange; that of hydrogen (Fig. 7), by a red, a green, and a blue line. Some are much more complicated.

281. The **dark lines are caused** by an absorption of the light of an incandescent solid or liquid by the refracted rays of a burning gas. Thus the continuous spectrum becomes an absorption spectrum when the light which produces the former passes through the vaporous light which would produce a spectrum of bright lines; and in the absorption spectrum, the dark lines occupy precisely the same position as the bright lines in the line spectrum.

For example, when the brilliant light emitted by incandescent lime is made to pass through a flame colored by sodium, the spectrum presented shows a dark line in place of the bright yellow line of the sodium spectrum, the sodium light absorbing the rays of the same refrangibility as those which it emits, and allowing the others to pass unchanged. In fact it stops those rays, leaving those lines to be illuminated only by the comparatively feeble light of the sodium flame, so that they appear dark by contrast with the other parts of the spectrum.

The dark lines in the *solar spectrum* are attributed to the vapors of substances in the gaseous envelope of the sun which absorb some of the rays emitted by the incandescent or liquid mass within. The dark lines in the solar spectrum correspond to the bright lines of the spectra of well-known substances, as sodium, iron, etc., showing that such substances exist in the sun's atmosphere.

The *spectra of the stars* present considerable variety. They have been distinguished (by the Italian astronomer Secchi) into four types, or classes:

(1) Those of the white stars, such as Sirius and Vega (a Lyræ) (Plate I., Fig. 12), which contain a number of very fine lines, and always four dark lines coinciding with the bright lines of hydrogen—out of 346 stars, 164 were found to belong to this class; (2) those which are crossed by numerous fine lines like those of the solar spectrum, of which those of Capella and Pollux are examples; (3) those of red and orange stars, as those of Alpha in Orion (*a* Orionis), Beta in Pegasus (*β* Pegasi), etc. (see Plate I., Figs. 12, 13, and 14); and (4) those of small red stars having spectra containing three bright zones increasing in intensity toward the violet. Thus it would seem that the physical constitution of the stars, while resembling that of the sun, differs from it in the elementary substances which they contain.*

282. The **spectroscope** is an instrument used for the examination of the spectra of different kinds of light.

It is composed of three telescopes, A, B, and C (Fig. 185), mounted on a

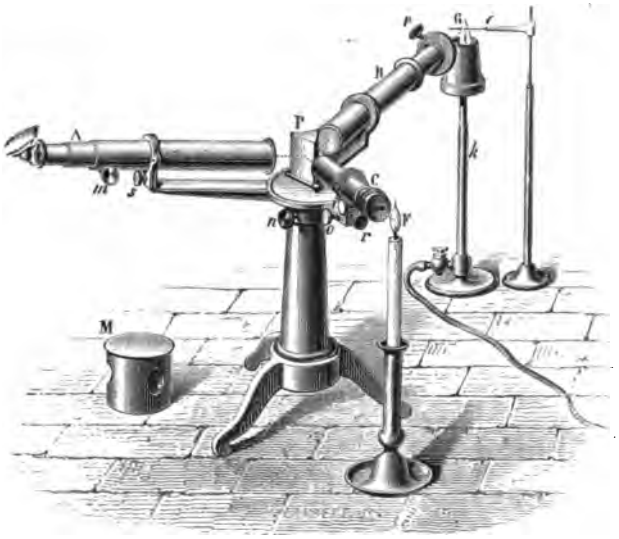


Fig. 185.

common foot, and pointing toward a prism, P, of flint-glass, of which A is adjustable both vertically and horizontally. The light from G passes through the telescope B, and enters as a beam of parallel rays the prism P, by which it is

* "The atmosphere of the star Aldebaran contains hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury. The atmosphere of the star Alpha in Orion contains sodium, magnesium, calcium, iron, and bismuth. No star sufficiently bright to give a spectrum has been observed to be without lines."—*Tyndall.*

decomposed, forming a spectrum that is magnified by means of the telescope A. C is used for measuring the lines. A scale of equal parts is placed at the end next the light F, and a magnified image of this scale is seen by the observer looking through A. This serves as a standard of reference by which to measure the positions and intervals of the spectral lines.

The *direct vision spectroscope* is represented in Fig. 186. A series of two flint-glass and three crown-glass prisms are placed in a tube which slides in a second



Fig. 186.

one, at the end of which is an aperture, *o*, and inside it a slit which can be regulated by turning a ring, *r*. The light passes through this slit, and is converted into parallel rays by the lens *a a*; they then traverse the train of prisms, and the spectrum is seen at *e*.

283. **Spectrum Analysis.**—The presence of the vapor of any metallic substance in a flame being always indicated by the spectrum made by its light, a method of chemical analysis is thus supplied of great delicacy and practical value. This is called *spectrum analysis.*

Physicists having accurately ascertained the lines produced by all known metals, can discover the existence of new metals by the presence in the spectrum of other lines. In this way rubidium and cæsium were discovered by Bunsen and Kirchhoff, and thalium by the English physicist William Crookes. The spectrum of the latter is characterized by a single green band. A very small quantity of the substance is sufficient to indicate its presence in the spectrum. The metal sodium (base of common salt) is particularly sensitive in this respect. The one two-hundred-millionth of a grain of it will cause the appearance of its yellow line. This yellow line, by a combination of prisms causing a greater dispersion, may be resolved into two or three lines.

The spectroscope has an important application in physiology and the diagnosis of disease; as in examining the blood and other fluids of the system for the detection of abnormal substances. The absorption lines presented by wine, beer, etc., afford a delicate test of their genuineness.

284. **Calorescence.**—By excluding all the rays of the spectrum of solar or electric light except the invisible heat rays, and interposing incombustible substances, the latter may be made incandescent, thus changing the non-luminous into luminous rays. This phenomenon is called *calorescence.*

285. **Fluorescence.**—In a similar manner the invisible rays beyond the violet may be made visible by allowing them to fall on

certain substances, for example, on the sulphate of quinine. This is called *fluorescence.*

In calorescence the refrangibility of the rays is increased by contact with a body, the atoms of which are thrown into a more rapid vibration than the ether waves which fall on it; but in fluorescence the refrangibility of the chemical rays is diminished, because the ether waves give a slower vibration to the atoms of the fluorescent body. "Thus," says Prof. Tyndall, "by exalting the refrangibility of the ultra-red rays, and by lowering the refrangibility of the ultra-violet rays, both classes of rays are rendered capable of exciting vision." *

286. **Chromatic Aberration.**—Owing to the unequal refrangibility of the colored rays, ordinary lenses give images with colored edges. This is called *chromatic aberration.*

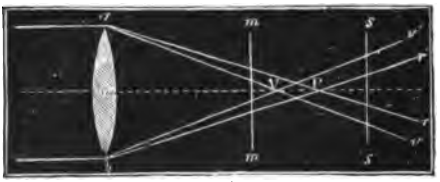


Fig. 187.

A lens may be compared to a series of prisms with infinitely small faces united at their bases; hence, it decomposes while it refracts the rays. There must, therefore, be a focus for every color, the red rays (the least refrangible) having their focus at R (Fig. 187), while the violet (the most refrangible), form a focus at V. Thus, if a pencil of rays passing through a convex lens fall on a screen at *m m* within the focal distance it will show a bright spot with a red border; if at *s s*, a bright spot with a violet border.

287. **Achromatism** is a term applied to the refraction of light without dispersion, and hence without color.

This can be accomplished by combining prisms which have different refracting angles, and are formed by substances of unequal powers of dispersion; also by combining lenses of different substances. Lenses constructed in this way are called *achromatic lenses* (*achromatic*—free from color).



Fig. 188.

The first achromatic lenses were constructed by an English philosopher, named Hall, in 1733; but Dolland, a London optician, rediscovered the principle, and brought it into practical use by combining a double-convex lens of crown-glass, B (Fig. 188), with a meniscus of flint-glass, A. The dispersive power of these substances being different, they are so adjusted in the lens that one corrects the other. As the refracting power of these bodies does not vary in the same ratio as the dispersive power, the refraction of the rays takes place without dispersion.

* "In strictness we cannot speak of rays being either visible or invisible; it is not the rays themselves but the objects they illuminate that become visible. Space, though traversed by the rays from all suns and all stars, is itself unseen. Not even the ether which fills space and whose motions are the light of the world, is itself visible."—*Tyndall.*

This is not true of all substances. Newton's experiments with glass and water convinced him that it was impossible for refraction to be effected without dispersion; and this conclusion was accepted for about half a century, till Hall renewed the investigation, and proved the possibility of achromatism.

The principle may be briefly explained in the following manner. The dispersive power of a prism, and therefore of a lens, depends upon its refracting angle, as well as the substance of which it is composed. Therefore, if a prism of crown-glass, B C F (Fig. 189), be combined with one of flint-glass, A C F, having a smaller refracting angle, but in an inverted position, so that both together may still have the form of a prism, it is obvious that the dispersive powers which are equalized by the difference in the refracting angles, will be neutralized by their contrary positions. The prism thus composed will refract the rays S I, but will not disperse them, the emergent rays, E O, being white light. The same effect is produced by the combination of the double-convex lens of crown-glass and the meniscus of flint-glass.



Fig. 189.

As the refracting angles proper for the neutralization of the red and violet rays are not perfectly suited for that of the intermediate rays, the achromatism produced in this way is not absolutely complete.

288. **Rainbow.**—The phenomenon of the rainbow is caused by



Fig 190.

the decomposition of the sun's rays in passing through the drops of rain, which refract the light like a prism.

To explain this, let n (Fig. 190) be a drop of water on which a solar ray, S a, impinges at a, where it is refracted passing through the drop in the line $a\ b$. At b it is reflected by the inner surface of the drop, in the direction of $b\ g$, emerging at g, where it is refracted in the direction of g O. The light that enters the eye at O has thus undergone one reflection and two refractions. It is not all the ray

S a, since a part is reflected outward at a, and a part passes outward at b. The angle formed by the incident ray S a and the emergent ray g O is called the *angle of deviation*. As the colored rays are unequally refrangible there must, obviously, be a different angle for each. This for the red rays is 42° 2′, and for the violet 40° 17′, between which the band of colors forming the rainbow is produced. Of course, every eye sees a different bow; and if it were sufficiently elevated, the bow would become a circular band. The bow is finest when it is formed by the rising or the setting sun.

Besides the bow described, there is an outer bow called the *secondary bow*, formed by another series of rain-drops. The drop p (Fig. 190) receives the ray S′ I at i: and, after two reflections, at d and f, it emerges at e, and reaches the eye at O, the angle of deviation being S′ I O. The minimum angle from violet rays is 54° 7′ and for red rays 50° 57′; hence the colors are in the reverse order from the inner bow, the violet being on the outside and the red on the inside. As there is a loss of light for every internal reflection, the secondary bow is fainter than the primary. The former ceases to be visible when the sun is 54° above the horizon; the latter, when it is 42°. There are lunar as well as solar rainbows, but they are very faint.

V.—OPTICAL INSTRUMENTS.

289. A **microscope** is an instrument used to obtain a magnified image of a minute object. It is either simple or compound.

290. The **simple microscope** is a double-convex lens suitably mounted for convenient observation.

The principle upon which it enlarges the apparent size of an object has already been explained. (See Art. 268.)

291. The **compound microscope,** in its simplest form, consists of two convex lenses, one of short focus, called the *object-glass* or *ob-*

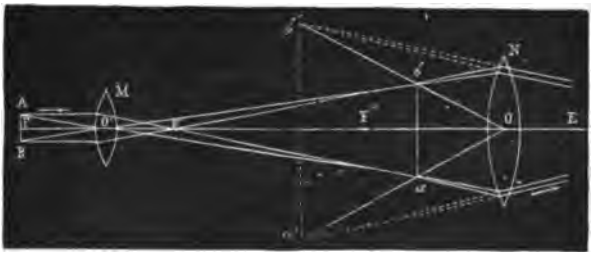


Fig. 191.

jective, because turned toward the object; and the other of longer focus, called the *eye-piece*, because close to the eye. These two

lenses are so adjusted that the magnified image formed by the objective may be still farther enlarged by the eye-piece.

This combination is seen in Fig. 191. The distance between the two lenses M and N is such that the position of the real image $a\ b$ is between the eye-piece N and its focus F. Hence an enlarged virtual image, $a'b'$, is produced; the eye-piece N acting as a simple microscope to magnify the image made by M, which is larger than the object because the latter is placed near the principal focus of the objective. As the image formed by M is inverted, and N does not change its position, the eye at E sees the object A B inverted. (Art. 268.)

In Fig. 192 is shown a perspective view of a compound microscope with its

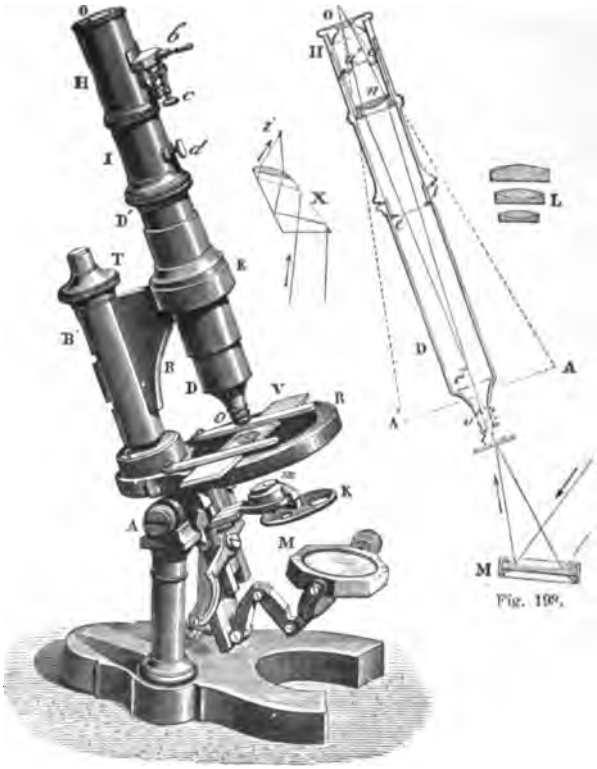


Fig. 192.

Fig. 191.

usual appliances; Fig. 193 presents a section of the same. O is the eye-piece and o the objective. The tube I slides in the tube D D', which can be moved in a larger tube fixed in the ring E. The whole body of the instrument can be raised

or lowered so as to be brought within any required distance of the object to be examined, which is usually placed between two glass plates, V, on a *stage*, R, perforated so that light may be reflected through it by a concave mirror, M, which is mounted so as to be adjusted to any position. K is a diaphragm, movable by the lever *n* to regulate the light; and *m* is a perforated piece to limit the light still further, or for the attachment of a lens to illuminate the object, or a prism, as shown at X.

The position and action of the lenses are illustrated in Fig. 193. The object-glass at *o* consists of three small convex lenses (represented on an enlarged scale at L), the combined effect of which is the same as that of a very powerful lens; while spherical aberration is avoided (Art. 270). A little beyond the principal focus of this is placed the object, *i*. If the eye-piece were a single lens, there would be chromatic aberration, to avoid which, two lenses, N and O, are used. The enlarged image *a a'* is seen at A A' still further enlarged. By *focusing*, the image *a a'* is formed not only between the lens O and its principle focus, but at such a distance from the lens that the image A A' may be formed at the observer's distance of distinct vision.

The magnifying power of a compound microscope is the product of the magnifying powers of the object-glass and eye-piece; thus, if the one magnifies 20 times and the other 10, the total magnifying power is 200. For definite and well-illuminated images a power of 500 or 600 diameters is as great as can be used; though a power of 1,500 diameters has been obtained. A power of 500 diameters gives a surface enlargement of 250,000 $(500)^2$ times; of 1,500 diameters, a surface enlargement of two and a quarter million times. By an exact measurement of the image, we can ascertain the absolute size of the object, when we know the magnifying power of the microscope.

292. A **telescope** is an instrument used to obtain a magnified image of a distant object. Telescopes are either celestial or terrestrial, the former being used for observing the heavenly bodies, the latter for viewing terrestrial objects.*

293. The **astronomical telescope** is of the simplest construction, consisting of a convex lens, called the *object-glass*, to produce an image of the distant object (Art. 268), and another convex lens, called the *eye-piece*, which acts as a simple microscope to enlarge the image. (Art. 290.)

294. Instead of using a convex lens as an object-glass to produce

* The invention of the telescope is attributed by some to Roger Bacon, who lived in the thirteenth century; by others to Baptista Porta, at the end of the sixteenth; while still others give the credit to Jacques Metius, a Hollander, who, in 1609, happened to find that by combining two lenses, one convex and the other concave, distant objects appeared larger and nearer. Galileo was the first to examine the heavenly bodies with a telescope, and by its means discovered the spots on the sun, the mountains in the moon, and the satellites of Jupiter.

an image, a concave mirror may be employed. (Art. 250.) Hence astronomical telescopes are of two kinds, those in which only lenses are used, called *refracting telescopes*, and those in which a concave mirror is employed, called *reflecting telescopes*.

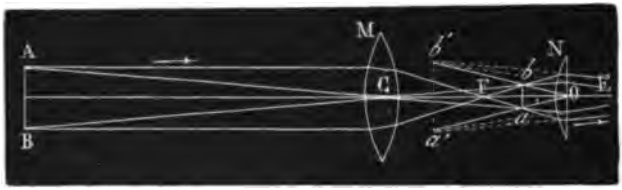


Fig. 194.

The arrangement of the lenses in an astronomical telescope is shown in Fig. 194. The object-glass M forms an inverted image, *b a*, of the distant object A B between the eye-piece N and its principal focus; and the eye-piece produces a virtual image, *a' b'*, much enlarged. The difference between a microscope and a telescope consists in the position of the object in regard to the object-glass. In the microscope, the object being near the lens, the image is at distance, and en-



Fig. 195.

larged so that both lenses magnify the image; in the telescope, the object is at a great distance from the object-glass, and hence the image is near the principal focus of the lens, and smaller than the object; so that the image is magnified only by the eye-piece, which, therefore, is of short focal length. (Art. 268.)

An astronomical telescope, mounted on a simple stand is shown in Fig. 195. The small telescope *a* attached to it is called the *finder*, because being of smaller magnifying power, it has a larger field of view than the large telescope, and is so adjusted that any object that appears in the center of its field, will be seen in the field of view of the larger instrument.

The magnifying power of a telescope is very nearly equal to the ratio of the focal length of the object-glass to the eye-piece; that is, if the focus of one were 10 feet, and the other ¼ inch, the magnifying power would be about 480 ($10 \times 12 \div \frac{1}{4}$). With sufficient light, the power may be much greater than this.

The object-glass should be of large diameter, so as to collect as much light as possible for the illumination of the image. The value of an astronomical telescope depends both on its light-collecting and magnifying capacity. The object-glass of the telescope used in the Washington Observatory has a diameter of 26 inches, and collects about 7,000 times as much light as the naked eye. Such a glass is, of course, of long focal distance; and hence requires a long tube, and very numerous and complicated appliances for its proper management.

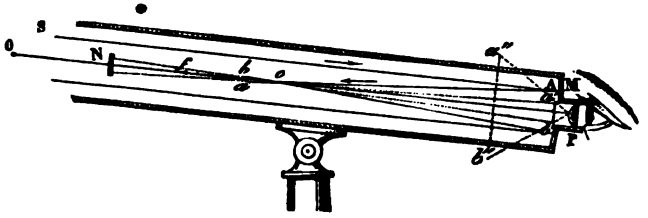


Fig. 196.

295. The **reflecting or catoptric telescope** has various forms, the principal of which are those devised by Gregory, Newton, and Herschel.

The *Gregorian telescope* consists of a long brass tube closed at one end by a concave metallic mirror, M (Fig. 196), having in the center an aperture through which the rays reach the eye. A small concave mirror, N, near the end of the tube, of small radius of curvature, which reflects the inverted image *b a*, formed

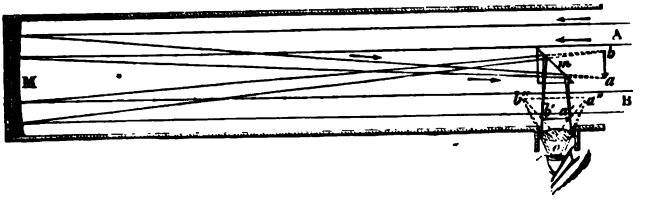


Fig. 197.

by M, and magnifies it at *a' b'*, where it is farther magnified by a convex lens, P, and seen as *a'' b''* in an erect position. The curvatures of the mirrors and

their distances from each other are so adjusted that the image $b\ a$ is between the center, o, and the focus, f, of the small mirror, so as to produce the magnified image $a'\ b'$ (Art. 250).

In the *Newtonian telescope*, the observer, instead of looking through an aperture in the large mirror, M (Fig. 197), views the image $a\ b$ through an eye-piece placed in the side of the telescope, this image being reflected to it by a small plane mirror, or a rectangular prism, m, which produces by total reflection (Art.

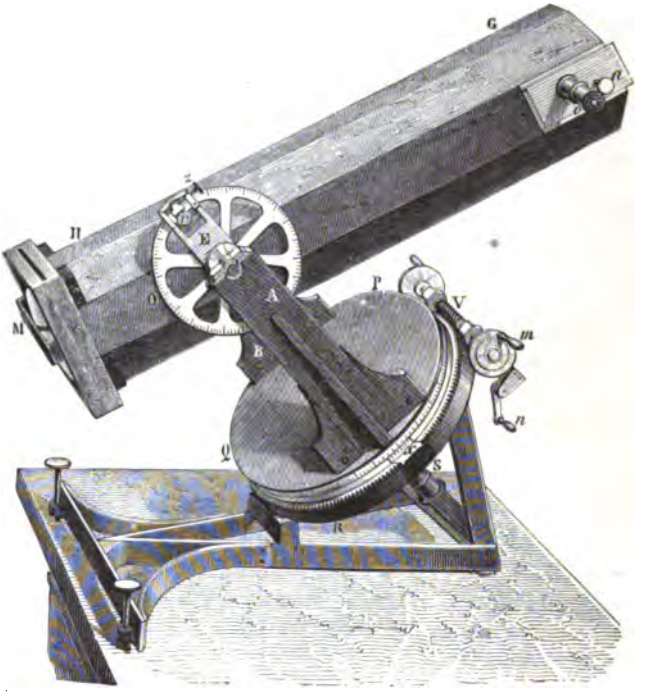


Fig. 198.

260) a small image, $a'\ b'$, which is magnified by the eye-piece. The mounted instrument is seen in Fig. 198, the eye-piece being at a, the open end at G, and the mirror at the other end.

Herschel's telescope, a section of which is shown in Fig. 199, was constructed somewhat differently; the mirror M was inclined so that the image was formed at $a\ b$ on the side near the eye-piece o; the rays undergoing only one reflection. This instrument, constructed in 1789, was 40 feet in length. It was, however, greatly exceeded by Lord Rosse's telescope, which has a focal length of 53 feet, and a mirror six feet in diameter, collecting 120,000 times as much light as the naked eye. In these instruments, the metal speculum, or mirror, is not circular, but parabolic, so as to avoid spherical aberration; and, of course,

there is no chromatic aberration. Silvered glass mirrors have recently taken the place of metallic mirrors; they have the advantage of weighing less, of giving purer images, and of a shorter focal distance. Besides, silver has better reflecting power than speculum metal.

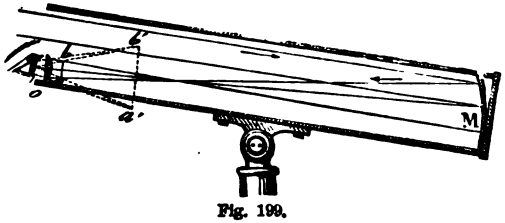


Fig. 199.

296. The **terrestrial telescope** is one that produces an erect image of the object viewed.

Among reflecting telescopes the Gregorian, which gives an erect image, may be used for terrestrial observation; but usually a modification of the refracting telescope is employed. This is effected by means of two convex lenses, P and

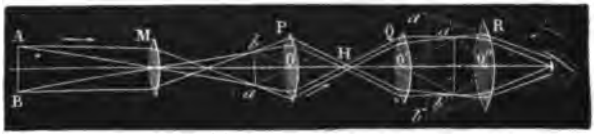


Fig. 200.

Q (Fig. 200), placed between the object-glass M and the eye-piece R. The first of these is so placed that the inverted image $b\ a$ is at its principal focus; thence the rays passing through P fall upon Q as parallel rays, and produce a re-inverted image, $a\ b$, in its principal focus (Art. 267), which is viewed through the eye-piece R, and produces the erect virtual image $a''\ b''$.

The lenses P and Q placed together in a brass tube constitute an *erecting eye-piece.*

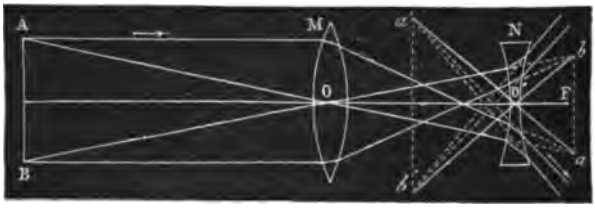


Fig. 201.

In *Galileo's telescope* this is accomplished in a much simpler manner, as shown in Fig. 201. It consists of a double-convex lens, M, used as the object-glass, and a double-concave lens, R, as an eye-piece, which gives, without any other appli-

ance, an erect image. For, let the object be conceived at a distance in the direction of A B, so that a real but inverted and smaller image, *b a*, would be formed by M near its focus (Art. 268); but the rays from A B passing through the concave lens R, are refracted and form an enlarged and reinverted image, *a' b'*. The eye-piece can be moved to and from the object-glass so as to form the image *a' b'* at the distance of distinct vision. As the distance of R from the image *a b* is nearly equal to the principal focal distance of this lens, the distance between the lenses must be the distance between their respective focal distances. Hence this form of telescope is short and portable. It is employed in the opera-glass, which is made double to increase the brightness, by producing an image in each eye. Both object-glass and eye-piece should be achromatic lenses.

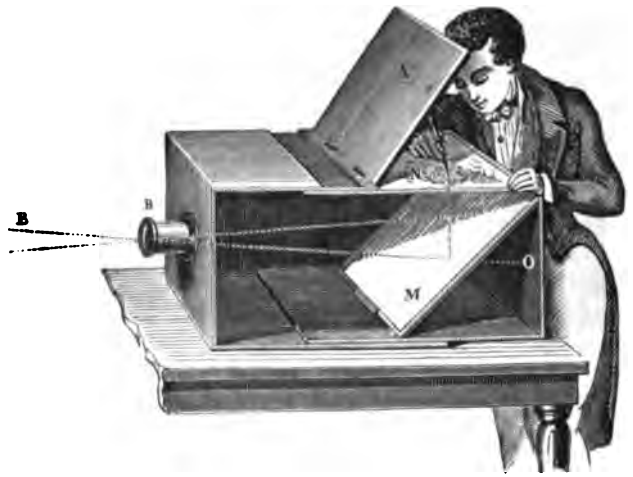


Fig. 202.

297. **Camera Obscura.**—The *camera obscura* (dark chamber) is a closed space into which the light is admitted through a double-convex lens fixed in an aperture, and falls upon a white screen placed in the focus of the lens, producing small and inverted images of external objects.

One form of this apparatus is shown in Fig. 202, which consists of a rectangular wooden box formed of two parts that slide in and out for the purpose of focusing. The rays R pass into the box through a lens, B, and would form an image on the opposite side O, at the focal distance of the lens; but they are intercepted by a plane mirror, M, inclined at an angle of 45°, which reflects them upon a ground-glass plate, N, from which the picture can be taken on a piece of transparent tracing-paper. The door A is used to cut off extraneous light.

The photographic camera, represented in Fig. 203, is constructed on this

principle. The brass tube A contains an achromatic convex lens, adjustable by a screw, D. At the opposite side is a ground-glass plate, E, which slides in a



Fig. 203.

groove. When the instrument has been so adjusted as to produce the required image on this plate, it is removed and replaced by a sensitive plate, which receives, by action of the light, a picture, to be developed by chemical treatment.

298. The **magic lantern** is an apparatus by means of which magnified images of objects may be shown in a dark room on a white screen.

It consists of a tin box in which there is a lamp placed in the focus of a concave mirror, A (Figs. 204 and 205). The reflected rays fall on a convex lens, B,

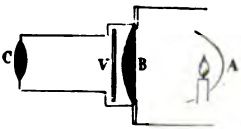


Fig. 204.

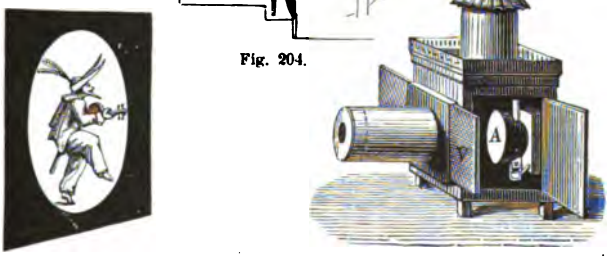


Fig. 205.

which concentrates them on the figure painted on a glass plate, V. A convex lens, C, at a distance from V rather more than its focal distance, forms a real

and very much magnified image of the figure on the glass, which is received on the screen.

The *solar microscope* is a magic lantern in which the light of the sun is used instead of a lamp. By means of it, in a dark room, highly magnified images of small objects can be thrown upon a screen; and many curious phenomena, such as the circulation of the blood in small animals, the crystallization of salts, etc., can be exhibited to a large assemblage of persons.

299. **The Human Eye.**—The eye is the organ of vision. It resembles, in its general structure, the camera obscura, the *pupil* being the aperture into the dark space, and the *retina*, a network of delicate nerves, being the screen upon which the pictures of external objects are formed.

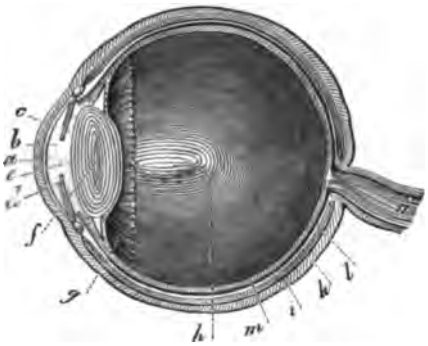


Fig. 206.

This is shown in Fig. 206, in which *a* is a transparent membrane in front, called the *cornea*, resembling a small watch-glass; *b* is a space, called the *anterior chamber*; *c* is the *posterior chamber*, these two chambers being filled with a transparent liquid called the *aqueous humor*; *d* is a circular muscle called the *iris*, in which there is an aperture called the *pupil*. The iris is involuntarily contracted and expanded, so as to make the pupil larger or smaller, and thus regulate the amount of light admitted into the eye; *f* is a double-convex transparent body called the *crystalline lens*, placed immediately behind the iris; it is less convex in front than behind; *h* is a transparent mass of liquid, called the *vitreous humor*, filling the inner space, and *m* is the *retina*, consisting of branches of the *optic nerve*, *n*. The *choroid*, *k*, is a membrane lining the inner surface, covered with a black substance, so as to absorb the rays; and *i* is a hard coating, called the *sclerotica*, which forms the outside wall of the optic chamber. The rays from A (Fig. 207) on passing into the aqueous humor (a meniscus) are, by refraction,

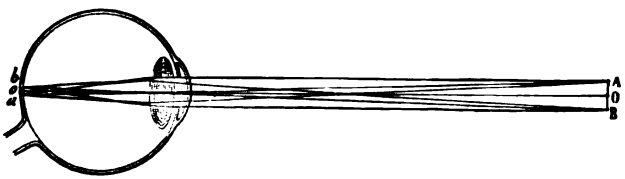


Fig. 207.

brought near the secondary axis A a, passing through the optic center of the crystalline lens; they are again refracted by the latter lens, and finally by the *vitreous humor* (a meniscus), and brought to a point on the retina at a; in like manner the rays from B come to a point at c; so that a small and inverted image of the object is formed between a and b. Though the sensuous image is inverted, the mind is so constituted as to *perceive* everything in its erect position.

The *visual angle* is that under which an object is seen. Its size depends on the distance of the object. Thus the angle A O B, under which A B (Fig. 208) is seen, is much smaller than A′ O B, under which the same object is seen at a greater distance. The apparent size of an object depends on the visual angle under which it is seen.

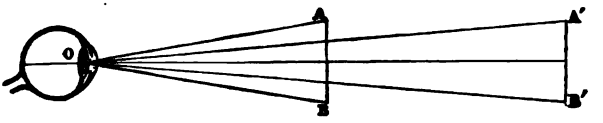


Fig. 208.

Short sight (*myopy*) is caused by a too great convexity of the cornea, which causes the rays to converge to a point in front of the retina; *long sight*, on the contrary, arises from an insufficient convexity of the cornea, so that the rays converge behind the retina. The one may be corrected by the use of eye-glasses with concave lenses; the other by double-convex lenses. Instead of these, as proposed by Wollaston, concavo-convex lenses (C and F, Fig. 167) may be used, so placed that their curvature is in the same direction as that of the eye. These are called *periscopic glasses*, as they give a much wider range.

The eye involuntarily adapts itself to the varying strength of the light by the muscular expansion and contraction of the iris, making the pupil larger or smaller, so as to admit a greater or less quantity of rays. The eyes of some animals have this power of adaptation to a remarkable extent. Thus the owl can, by the enlargement of the pupil of its eye, see in almost total darkness, as also the cat: but the former is dazzled by daylight, because the construction of its eye renders it excessively sensitive to the light.

300. **The Stereoscope.**—In ordinary binocular vision, objects appear in relief. The same effect is produced by looking at a double representation of an object in a *stereoscope*.

Two perspective drawings are made of an object from such points of view as might be occupied by the two eyes in looking at it; and these drawings are placed in a box with two compartments, so arranged that each eye may look at its appropriate picture through a half lens, serving to magnify the virtual image and to displace it in such a way as to bring the two into coincidence. Photographs taken by a double camera, with two objectives, one beside the other like two eyes, serve as stereoscopic pictures.

The same principle applied to the magic lantern produces the *stereopticon*, which exhibits relief views of objects on a screen.

VI.—MISCELLANEOUS PHENOMENA.

301. **Irradiation** is a phenomenon in which white or very bright objects seen on a dark ground appear larger than they are.

For this reason a white square upon a black ground seems larger than an equal black square on a white ground. This effect is produced by the impression on the retina extending beyond the outline of the image. It is very perceptible in the apparent magnitude of the stars.

302. **Double refraction** is the separation of a ray of light into two rays, which takes place when it passes through certain crystalline substances, such as Iceland spar.

The phenomenon as shown in Iceland spar was first announced in 1669 by Bartholin, but the law of double refraction was first enunciated by Huyghens in 1690. It does not occur in substances that crystallize in cubes, or in substances, like glass, that are destitute of crystallization. They, however, acquire this property when they are unequally compressed, or when they are cooled quickly after being heated. Hence *unannealed glass* possesses it; but it exists in the highest degree in Iceland spar, or carbonate of calcium. When an object is viewed through this substance, it appears double. Of the two rays, one is called the *ordinary ray* and the other the *extraordinary ray*.

It is accounted for on the hypothesis that, in double-refracting bodies, the ether is not equally elastic in all directions; so that the vibrations in certain directions at right angles to each other are transmitted with unequal velocities, those directions depending on the character of the crystals. The extraordinary ray does not conform to the ordinary laws of refraction as to the sines of the angles, nor is the refraction in the same plane as the incident ray.

303. **Interference of light** is a phenomenon due to the action of one ether wave upon another, by which their effects are neutralized, the depressions of one being counteracted by the elevations of the other, so as to produce darkness instead of light. This is analogous to interference of sound.

The effect of interference may be shown by the following experiment: Let a beam of red light pass into a dark room through a convex lens, L (Fig. 209), so as to be brought to a focus, F, making a point of light; and from this let divergent rays fall on two plane mirrors, A B and B C, arranged so as to be almost in the same plane. Then the incident rays falling upon A B will be reflected in the direction F' A H, and those upon B C, in the direction F^2 C I. Thus each of the points H, I, and K on the screen S S′ is illuminated by two sets of rays, coming from the direction F^1 and F^2. Now, if the waves of these two rays coincided, the light would be uniform; but it is found that a series of parallel bands are formed alternately light and dark, showing the action of interference; for when either of the mirrors is removed the dark bands disappear. When the violet in-

stead of red rays are used, the distance between the dark lines is increased; and when white light is admitted colored bands are formed.

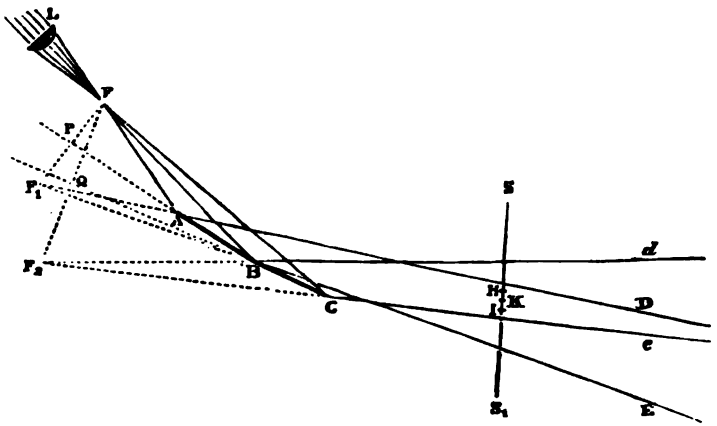


Fig. 209.

304. **Diffraction** is a phenomenon caused by an apparent bending of the rays of light when they pass a very sharp edge of an intervening object, so that they penetrate into the shadow of the object, and cause a faint illumination of it.

This is illustrated in Fig. 210. A beam of solar light is admitted through red glass into the aperture of a shutter, passing through the lens L, and is partly intercepted by the opaque screen *e* having a sharp edge, *a*, a part falling on the screen *b*, a front view of which is represented at B. It is then seen that, below the

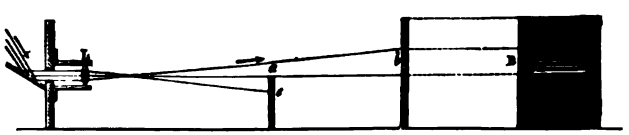


Fig. 210.

line *a b*, which is the geometric boundary of the shadow, there is a faint light which shades off into the dark surface of the screen, and above the line a series of dark and light bands or fringes parallel to the line, gradually becoming more indistinct. All the colors of the spectrum are found to produce the same appearance, except that the bands are wider in inverse proportion to the refrangibility of the rays, the red therefore being the widest and the violet the narrowest. With white, these bands present all the colors of the rainbow.

When the light from the luminous point is made to pass through a narrow slit

in an opaque screen a phenomenon is presented as shown in Fig. 211, the light being received on a white screen. This can be viewed through a small telescope from behind the aperture. These bands of light and shade, or of different colors, are called *diffraction spectra*, and are fully explained by the undulatory theory of light on the principle of interference. By changing the form of the aperture, or making the light pass through *gratings* of very fine lines ruled on glass, many beautiful effects may be obtained.



Fig. 211.

The diffraction bands afford a means of calculating the length of the ether-waves of color, from which it has been estimated that the wave-length for red is .000024 of an inch; and for blue, .000016 of an inch. From this and the velocity of light, the number of undulations in a second can be readily deduced. (Art. 271.)

305. **Colors of Thin Plates.**—Substances in thin transparent plates show by reflection bright and variegated tints. This is seen in the rainbow colors of large soap-bubbles, in a thin film of oil spread over a sheet of water, and in the flashing colors of a peacock's feathers and certain insects' wings. These are called the *colors of thin plates.*

306. **Newton's rings** constitute a phenomenon of a similar character, and due to the same cause—the interference of light.

In investigating the appearance of colored rings in soap-bubbles, Newton used a convex glass of large curvature placed in contact with a plane glass surface, as shown in Fig. 212. These surfaces being placed in front of a window so as to reflect the light, show at the point of contact a black spot surrounded by six or seven colored rings, the tints shading off in strength. With red light these rings are successively black and red; and the diameters diminish as the refrangibility of the color increases; while with white light they present the various colors of the spectrum.*



Fig. 212.

* Newton accounted for the rings according to the emission theory, by assuming that the light particles were endowed with "fits of easy transmission and of easy reflec-

The phenomenon is due to the interference of reflected rays and may be thus explained: Let M N O P (Fig. 213) represent a thin transparent plate, on which a pencil of rays, *a b*, falls. This will in part be reflected toward *b c*, and part refracted in *b d*. The refracted ray will be reflected from the surface O P in *d e*, this reflected ray emerging in *e f* parallel to *b c*. Thus there are two sets of waves very close together, and it is obvious that they will either intensify the effect or extinguish each other by interference.

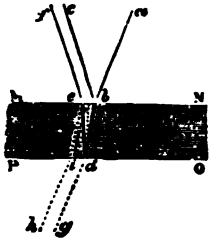


Fig. 213.

307. **Polarization of Light.**—A beam of light, by double refraction, or oblique reflection, at a certain angle, seems to acquire the property of having two sides, like a thin flat substance; this is called *polarization*.

Huyghens first observed the phenomenon in Iceland spar, by noticing that, when a ray which has been refracted by a crystal of that substance passes through a second crystal, at one position of the latter the ordinary ray disappears, and at another the extraordinary ray. This was accounted for by Newton, according to the emission theory, on the supposition that the particles of ether had different poles, which arranged themselves variously in different positions. The term *polarization* was not, however, permanently given to the phenomenon until it was seen in reflection by Malus in 1808.* This phenomenon is best investigated by means of the double-refracting properties of crystals of the mineral called tourmaline.

Take two thin plates of a tourmaline crystal cut parallel to the axis, and it will be found that a beam of light which passes through one will pass through the other also, provided they are held in similar positions, that is, if the axes of the two plates are parallel. But if they are perpendicular, the light that passes through one is stopped by the other; while if they are oblique, only a part of it is transmitted. From this it follows that if between two plates of tourmaline perpendicular to each other, a third plate be introduced obliquely, light will pass

tion." But, as Tyndall says, "the rings are referred by the undulatory theory to the interference of rays which have passed directly through the film with others which have undergone two reflections within the film. They are thus completely accounted for."

* "It was while gazing one evening in 1808, through such a prism of Iceland spar as we have just described, at the windows of the Luxembourg Palace, in Paris, that M. Malus, at that time engaged in studying the law of extraordinary refraction in this body, happened to notice that the reflection of the sun on a window of the palace disappeared from one of its images, in a certain position of the prism, and from the other when held at right angles to that position; while in the intermediate situations, the glare was visible in both images, unequally divided, however, between them, except when held in a situation exactly intermediate, or at 45° from its first position—in a word, that the light reflected from the window had acquired precisely the peculiarity which would have been impressed on it by previous transmission through a similar prism. To this peculiarity he gave the name *polarization*, and light so affected has ever since been said to be polarized."—*Sir John Herschel.*

through the three, since a part will pass from the first through the second, and a part again from the second through the third.

The undulatory theory explains this by conceiving that the ether vibrations constituting a ray of light are in different directions, *transversely* to the line of propagation (unlike those of sound, which are lengthwise); and that, in passing through substances of a certain structure, the ray is changed so that the vibrations take place only in one transverse plane, corresponding to the structure of the substance; therefore, when the ray has been thus changed, it can entirely pass through the substance only in the one way, and when its position is reversed the ray is stopped, just as a thin board can only be passed in one position through a grating; and, if passed through one grating would be stopped by another held in the reverse position.

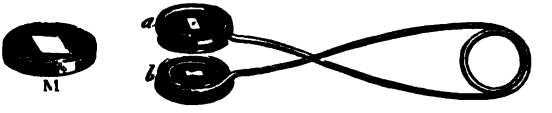


Fig. 214.

308. **A polariscope** is an instrument used to observe polarized light. It consists of two parts, one for polarizing the light, called the *polarizer;* and the other for seeing it, called the *analyzer.*

This is shown in the *tourmaline pincette* (Fig. 214), which consists of two tourmaline plates cut parallel to the axis, each fitted in a copper disc, M, blackened and perforated in the center. These two discs are mounted in two rings of silvered copper, bent and coiled in such a manner as to form a spring, as shown in the figure; and are fitted so as to turn with the disc, in order that they may be arranged with their axes parallel or perpendicular to each other. The substance to be examined is placed between the discs, of which the one nearest the eye acts as the analyzer and the other the polarizer.

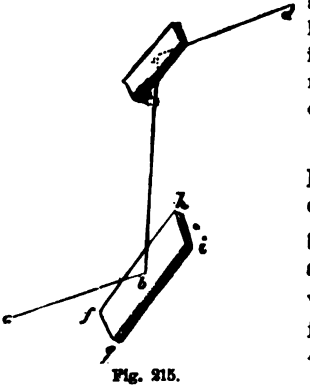
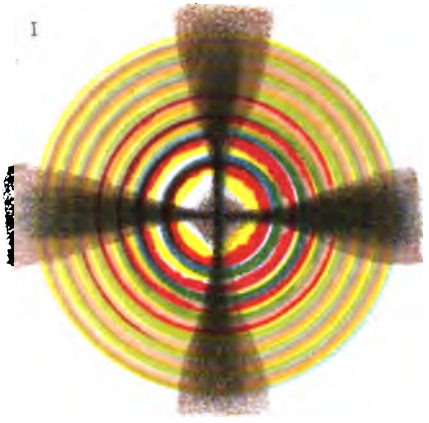


Fig. 215.

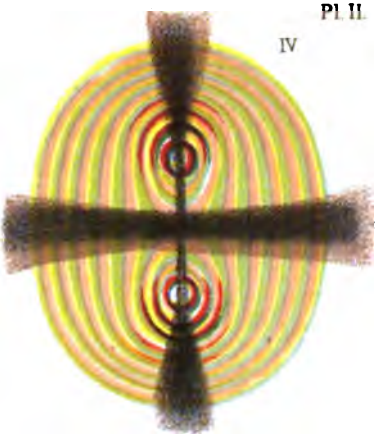
309. **Polarization by reflection** takes place when the rays of light are reflected obliquely from polished surfaces, such as glass and water. The effect is greatest at a certain angle of incidence, which varies for each particular substance, that for glass being 54° 35′. This is called the *polarizing angle.*

Let a ray of light, *a b* (Fig. 215), fall on a polished unsilvered glass surface, *f g h i*, so that the angle of incidence may be 54° 35′; the reflected ray, *b c*, will then be polarized; and if it be received on

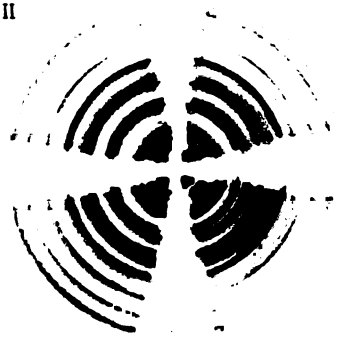
I



IV



II



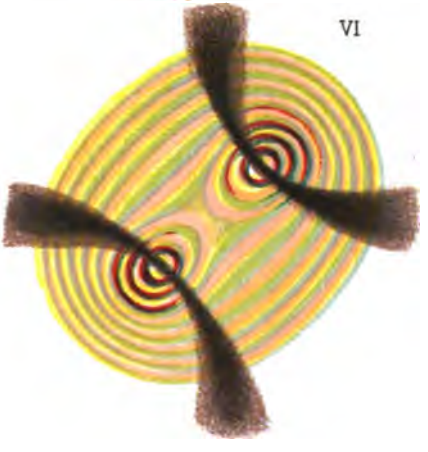
V



III



VI



H. BENGKE, LITH. N.Y.

a similar glass surface at *c*, at the same angle, it will be found that as long as the surfaces are parallel, the ray will be reflected, but if the second be turned around the first, the reflected ray will grow less and less distinct, until, when the surfaces are at right angles with each other, it will wholly disappear.



Fig. 216.

Or it can be ascertained that the reflected ray has undergone the change called polarization by letting it pass through a crystal of Iceland spar; for it will be found that only the ordinary ray is transmitted when the principal plane of the crystal is parallel to the plane of reflection; and the extraordinary when these planes are at right angles to each other.

The polarizing angle for water is 52° 45′; for quartz, 57° 32′; for the diamond, 68°. Light reflected from the surface of water, from polished furniture, and all other except metallic surfaces, is more or less polarized; as are also the solar rays when they fall obliquely on the atmosphere in the morning or afternoon.



Fig. 217.

310. The polarizing angle of a substance is always that angle of incidence at which the polarized reflected ray is at right angles to the refracted ray.

This law was discovered by Brewster. It may be illustrated as follows: Let *s i* (Fig. 216) represent the incident ray, *i r* the refracted ray, and *i f* the reflected ray; then the effect of polarization is greatest when the angle *f i r* is a right angle.

In *Norremberg's apparatus* (Fig. 217), the polarization of light is beautifully illustrated. A ray of solar light received on the glass surface at *n* at the polarizing angle, is reflected to a mirror at *p*, and again reflected upward to *r* on a blackened glass surface, *m*, inclined at the polarizing angle. This surface, *m*, can be revolved on the circular disc *o*; and when its position is, as represented in the figure, such that the plane of incidence on the upper mirror is perpendicular to the

plane of incidence $s\ n\ p$, there is no reflection from m; but as m is revolved, the reflected light increases, and reaches its maximum when the mirror m is parallel to the mirror n. If the mirror m is at a greater or less angle than that of polarization, more or less of the light is reflected during an entire revolution.

311. **Colored rings** are produced by polarized light, similar to Newton's rings, when the rays traverse two thin plates of a double-refracting substance.

These, as exhibited by a polariscope, are represented in Plate II. Fig. I. shows the result when the rays traverse two thin plates of Iceland spar, having their axes perpendicular. When they are parallel, the black cross becomes white, as shown in Fig. II., and the colors are complementary to the former ones. The effects with other substances, and in other positions of the tourmalines constituting the polarizer and analyzer, are shown in Figs. III., IV., V., and VI.

The observation of crystalline substances by means of polarized light has become a very delicate test of their composition and character. The *saccharimeter* is a polarizing instrument for the examination of the crystals of sugar.

The rays of heat, like those of light, may also become polarized by reflection and refraction.

SYNOPSIS FOR REVIEW.

LIGHT, OR OPTICS.

I.—ORIGIN, TRANSMISSION, AND INTENSITY OF LIGHT.

1. *Theories:* 1. Emission, or corpuscular. 2. Undulatory.
2. *Definitions:* 1. Luminous and transparent. 2. Ray and pencil. 3. Divergent and convergent. 4. Medium. 5. Shadow.
3. *Velocity of Light—How found:* 1. Roemer's method. 2. Other methods.
4. *Intensity of Light.*—Photometer.

II.—REFLECTION OF LIGHT, OR CATOPTRICS.

1. *Law of Reflection.*
2. *Mirrors:*
 - 1. Plane: 1. Virtual image. 2. Multiple images. 3. Kaleidoscope. 4. Regular and irregular reflection. 5. Intensity of reflected light. 6. Heliograph.
 - 2. Curved: 1. Spherical.
 - 1. Concave: 1. Focus of parallel rays. 2. Of divergent rays. 3. Conjugate foci. 4. Real and virtual image. 5. Principal and secondary axes.
 - 2. Convex: 1. Focus of parallel rays. 2. Of divergent rays. 3. Virtual image. 4. Spherical aberration. 5. Caustics by reflection.
 - 2. Parabolic.
 - 3. Cylindrical and conical.

III.—REFRACTION, OR DIOPTRICS.

1. *Laws of Refraction.*—Index of refraction.
2. *Phenomena:* 1. Ordinary. 2. Astronomical refraction. 3. Total refraction (Critical angle). 4. Mirage.
3. *Refraction by Prisms.*—Polyprism.—Right-angled prism.
4. *Lenses:* 1. Different kinds. 2. Principal axis. 3. Focus.
 - 1. Convex: 1. Focus of parallel rays. 2. Of divergent rays. 3. Conjugate foci. 4. Optical center of lens. 5. Secondary axis. 6. Real and virtual image.
 - 2. Concave: 1. Virtual focus of parallel and divergent rays. 2. Virtual image. 3. Spherical aberration. 4. Caustics by refraction.

LIGHT, OR OPTICS.—(*Continued.*)

IV.—COMPOSITION OF LIGHT.

1. *Decomposition of White Light.*—Dispersion, or prismatic analysis.
2. *Solar Spectrum.*—Colors.—Cause of colors.
3. *Recomposition of White Light:*
 1. By prism.
 2. By lens.
 3. By mirror.
 4. By Newton's disc.
4. *Color of Bodies.*—Cause of. Absorption and reflection.
5. *Complementary Colors:*
 1. Spectral colors.
 2. Pigment colors.
6. *Chemical and Heat Rays.*
7. *Fraunhofer's Lines:*
 1. Discovery.
 2. Position in the spectrum.
 3. Cause.
8. *Different kinds of Spectra:*
 1. Continuous.
 2. Line.
 3. Absorption.
9. *Spectra of the Stars.*
10. *Spectroscope.*—Direct vision spectroscope.—Spectrum analysis.
11. *Calorescence and Fluorescence.*
12. *Chromatic Aberration.*—Achromatism.—Achromatic lens.
13. *Rainbow:*
 1. Cause.
 2. Primary and secondary bow.

V.—OPTICAL INSTRUMENTS.

1. *Microscope:*
 1. Simple.
 2. Compound.
2. *Telescope:*
 1. Astronomical:
 1. Refracting:
 1. Gregorian.
 2. Newtonian.
 3. Herschel's.
 4. Rosse's.
 2. Reflecting.
 2. Terrestrial.
 1. Erecting eye-piece.
 2. Galileo's telescope.—Opera-glass.
3. *Camera Obscura.*—Photographic camera.
4. *Magic Lantern.*
5. *Human Eye:* 1. Cornea. 2. Crystalline lens. 3. Aqueous humor. 4. Vitreous humor. 5. Retina. 6. Pupil. 7. Iris. 8. Sclerotic and choroid. 9. Visual angle. 10. Short and long sight.
6. *Stereoscope.*—Stereopticon.

VI.—MISCELLANEOUS PHENOMENA.

1. *Irradiation.*
2. *Double Refraction.* Cause.
3. *Interference of Light.*
4. *Diffraction.* Diffraction Spectra.
5. *Colors of Thin Plates.*
6. *Newton's Rings.*
7. *Polarization:*
 1. Phenomenon.
 2. Cause.
 3. Polariscope—Tourmaline Pincette.
 4. Polarization by reflection.
 5. Polarizing angle.
 6. Norremberg's apparatus.
 7. Colored rings.
 8. Analysis by polarization.—Saccharimeter.

APPLICATION OF PRINCIPLES.

Explain the following phenomena: 1. Why the rays of light seem visible when they enter a dark room through a small aperture. 2. Why the light instantly disappears when the gas is turned off, however large the room may be. 3. Why a person cannot see the image of himself in a plane mirror, unless he stand directly in front of it. 4. Why, when he looks obliquely into a plane mirror, he sees the images of objects at the other side of the mirror. 5. Why the image of an object in a plane mirror seems to be as far behind it as the light is in front of it. 6. Why an object sometimes appears double in a looking-glass, but not in a metallic mirror. 7. How the kaleidoscope forms so great a variety of figures out of a few objects.

8. Why it does not grow dark as soon as the sun sets. 9. How military signals can be sent by the heliograph. 10. When and why the image of an object is inverted in a concave mirror. 11. When and why it is erect. 12. When and why it is larger than the object. 13. Why the image of an object in a convex mirror is smaller than the object itself. 14. Why it is erect. 15. Why a stick held obliquely in the water seems bent or broken. 16. Why it seems straight when plunged perpendicularly into the water. 17. Why a river viewed obliquely from the bank seems more shallow than it really is. 18. Why, generally, we do not see the heavenly bodies in their true places. (Is a body seen in its true place when it is in the zenith, or exactly overhead? Why?) 19. Why bodies immersed in water seem nearer the surface than they really are.

20. How the phenomenon of mirage is caused. 21. Why objects seen through a prism appear surrounded with color. 22. Why refraction separates the differently colored rays that form white light. 23. Why the red is at one end of the solar spectrum, and violet at the other. 24. Why a prism is used to show this phenomenon. 25. Why objects illumined by white light are differently colored. 26. Why charcoal is black. 27. Why some objects are white. 28. Why the clouds at sunrise and sunset appear golden or red.

29. When and why the image formed by a convex lens is magnified. 30. When and why it is smaller than the object. 31. Why the image formed by a concave lens is smaller than the object. 32. Why near-sighted persons use eye-glasses with concave lenses. 33. Why old persons use eye-glasses with convex lenses. 34. Why substances burn in the focus of a double convex lens held in the sun's rays. 35. How "burning-mirrors" may be constructed.

36. Why the solar spectrum is crossed by dark lines. 37. Why the spectra of the stars differ from that of the sun. 38. How the rainbow is caused. 39. Why it is double. 40. Why the order of the colors in the secondary bow is the reverse of those in the primary. 41. Why the light is less distinct in the former than in the latter. 42. Why the rainbow cannot be seen at noon. 43. Why it is seen in the east in the evening and in the west in the morning. 44. Why the owl can see in the dark and cannot see in the light. 45. Why certain colors appear better together than others.

46. Why a lens of flint and crown glass is achromatic. 47. Why the apparent time of sunrise and sunset is not the true time. 48. Why objects are distorted when seen through glass of an irregular form or thickness. 49. Why the luminous rays of the spectrum are not used in taking a photograph. 50. Why an object looks double when it is seen through a piece of Iceland spar. 51. When and why the rays of light become polarized. 52. How the chemical composition of substances may be ascertained by means of the polariscope. 53. What produces the iridescent color seen on the surface of soap-bubbles.

CHAPTER VIII.

MAGNETISM.

I.—PROPERTIES OF MAGNETS.

312. **Magnets** are bodies which have the property of attracting iron. The agency that produces this property and its resulting phenomena is called *magnetism*.

This peculiar property is found to exist in the highest degree in an ore of iron known in chemistry as the magnetic oxide of iron, sometimes called the *lodestone*,* which was first found in Magnesia, in Asia Minor; from which circumstance it derived the name *magnet*. It is very abundantly found, especially in Sweden and Norway, where it furnishes an excellent quality of iron.

313. An **artificial magnet** is a bar or needle of steel which, having been rubbed with a natural magnet, has acquired magnetic properties. This is what is ordinarily meant by a magnet.

314. The **poles of a magnet** are the two ends, where the attractive force is the strongest. When a magnet is freely suspended one

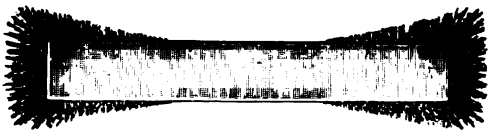


Fig. 218.

of its ends points toward the north, and the other toward the south. The former is called the *north* or *boreal pole* of the magnet, and the latter the *south* or *austral pole*.

When a magnet is placed in iron filings they become arranged round the

* The term *lodestone*—leading or guiding stone (from the Saxon *lædan*, to lead)—was given to the natural magnet, because when suspended it was observed to point in a certain direction.

ends, as represented in Fig. 218; while toward the middle there seems to be no attraction. This is called the *neutral line* of the magnet.

The existence of poles in a magnet constitutes what is called its *polarity*.

315. **Law of Attraction.**—Like magnetic poles repel, unlike poles attract, each other.

This can be shown by the apparatus represented in Fig. 219. Suspend a small magnetic needle, *a b*, by a fine thread, balanced at the center; then bring the north pole A of another magnet near the north pole *a* of the needle, and it will be repelled; but if A is brought near the south pole *b*, the latter will be attracted.

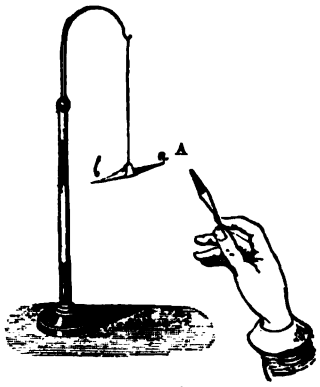


Fig. 219.

The same law may be illustrated in another manner. A piece of iron, a key, for example, is supported by a magnetized bar at A (Fig. 220). Now let a second magnetized bar of the same size, with reversed poles, be moved along the first; and as the south pole B approaches the contrary pole A, the key will drop.

316. **Magnetic Fluids.**—The phenomena of magnetism have been accounted for on the hypothesis that there are two subtle fluids

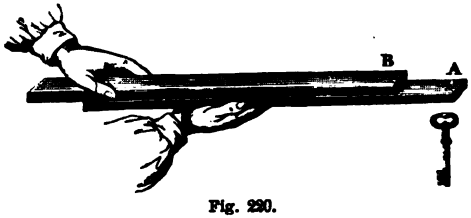


Fig. 220.

pervading this class of bodies, the fluid predominating at the north pole being called *red magnetism*, and that at the south *blue magnetism*.

These fluids, before a body is magnetized, are conceived to be combined around each molecule, in such a way as to neutralize each other, while they are capable of being separated by a force stronger than that of their mutual attractions. When a body becomes a magnet, they arrange themselves so that the one fluid is on one side of the molecule and the other fluid on the opposite side. Thus they impart polarity, both to the molecules and to the whole body.

That the fluids thus affect all the molecules is obvious from the fact that each half of a magnet broken at the neutral line is itself a magnet with two poles. This can easily be tested by experiment.

317. **Magnetic substances** are such as iron, steel, and nickel, which are attracted by the magnet.

A magnetic substance is not a magnet, since it has no poles, the two fluids neutralizing each other. Magnetic substances do not attract each other, and they attract the two poles of a magnet equally. Repulsion, not attraction, is thus the test of a magnet.

318. **Magnetic Induction** is the action of a magnet in changing a magnetic substance, as soft iron, into a magnet.

Thus, if a small piece of soft iron, *a b* (Fig. 221), be placed in contact with

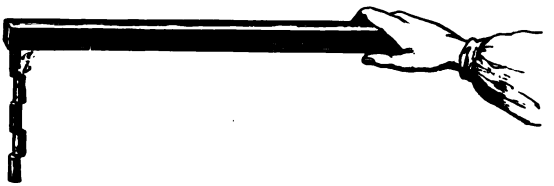


Fig. 221.

one of the poles of a magnet, it will support a second piece, and that a third, and so on, till the power of the magnet is exhausted. Each piece of iron is a magnet having poles like the large one. If *a b* is attached to the north pole of the magnet, *a* will be its south pole, and *b* its north pole; and in the next piece the poles will be reversed. If *a b* is removed from the magnet, all the others fall immediately, showing that they are magnets only while under the influence of the magnetized bar. Iron and nickel are only *temporary magnets;* steel and cobalt are *permanent magnets.*

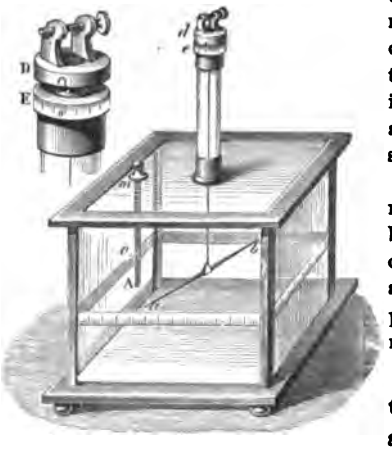


Fig. 222.

Soft iron becomes instantaneously magnetized by contact with a magnet, but does not retain the effect. Steel can also be magnetized, but very slowly, and must be rubbed with one of the poles. It, however, becomes a permanent magnet.

319. **Law of Magnetic Attraction.** — Magnetic attractions and repulsions are inversely as the square of the distances.

This was demonstrated by Coulomb by means of the torsion balance, as shown in Fig. 222. The magnetic needle *a b* is suspended in a glass case by a

very fine silver wire. The angle of the needle is measured by a scale on the side of the case, and the amount of torsion of the wire by a scale and micrometer at *e d*, shown on a larger scale at *E D*. At *m* there is an aperture for the introduction of a magnet, A. The force of torsion being proportional to the angle of torsion, it is possible by this contrivance to ascertain the exact amount of the magnetic attraction or repulsion under different circumstances.

When a magnet acts upon a mass of soft iron, the law of variation is different; the attraction being then inversely proportional to the distance of the magnet from the iron.

320. The law of magnetic attraction and repulsion may be presented to the eye by means of the *magnetic curves*, indicating the lines of force. The space within which this force is exerted is called the *magnetic field*.

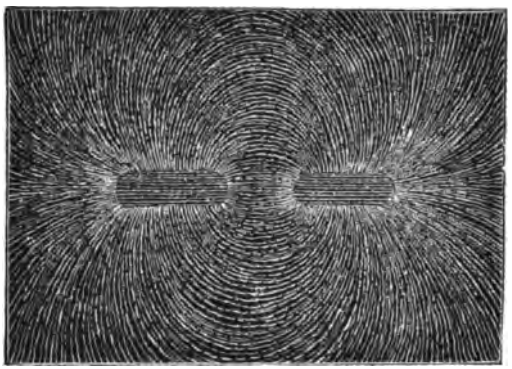


Fig. 223.

Take a thick sheet of paper and stretch it on a frame; and strew over it some very fine iron filings. Then on holding it over a horse-shoe magnet, and tapping the frame, the iron filings will arrange themselves in curves, as shown in Fig. 223. These lines extend from pole to pole, the direction corresponding to that of the magnetism at each point. If the paper be covered with a thin coating of wax before receiving the iron filings, the curves can when formed be rendered permanent by heating the wax, and then allowing it to cool.

Each pole it will be observed is a center of force, and if either pole be presented, end on, to the filings, they will arrange themselves in concentric circles.

When a piece of paper, as in the above experiment, is interposed between two magnets, the action of the magnets is not sensibly affected by it, nor is it affected by the magnetism. This is true of glass as well as paper, and of some other substances, which may, therefore, be said to be *magnetically transparent*.

321. A **magnetic battery** consists of a number of magnets united by their similar poles, either in a rectilinear or horse-shoe form.

The battery represented in Fig. 224 consists of twelve plates arranged in three layers of four each; that in Fig. 225 is composed of several steel plates in the



Fig. 224.

form of a horse-shoe. The latter form is best suited for supporting a weight, since both poles can be used at one time.

322. **Armatures,** or **keepers,** are pieces of soft iron placed in contact with the poles of a magnet, and kept there in order to prevent the loss of magnetism.



Fig. 225.

Thus A and B (Fig. 224) are armatures. Temporarily, they are themselves powerful magnets, with a polarity the reverse of the magnet to which they are attached. By reacting on the permanent magnetism of the steel, they preserve and even increase it.

The keeper of a horse-shoe magnet is usually so arranged as to support a weight, as represented in Fig. 225; or sometimes with an additional weight, as in Fig. 226. The keeper becomes strongly magnetized under the influence of the two poles, and adheres with great force. The weight which it can support is twice as great as that which can be sustained by either pole.

If the greatest possible weight be attached to the keeper, and left in contact for a day, it will be found to bear an additional weight, and this may be farther increased from day to day, until a maximum is reached. When contact is broken, however, the original weight is all that it will bear.

323. **Increase of temperature** always diminishes the magnetic force; and when a magnet has been strongly heated, it does not on cooling regain the force lost; while, if heated to redness, it is entirely demagnetized.

324. **Magnetization** is effected in various ways, chief among which are the methods by *single touch*, *separate touch*, and *double touch*.

The method by single touch consists in moving, several times, the pole of a powerful magnet along the bar to be magnetized, from one end to the other. In

that by separate touch, the two opposite poles of two magnets of equal strength are placed in the middle of the bar to be magnetized, and moved simultaneously toward the opposite ends of the bar. This process is repeated several times. When the method by double touch is used, the two magnets are placed with their poles opposite each other, close together, but separated by a small piece of wood, in the middle of the bar to be magnetized, and are moved together alternately from one end of the bar to the other.

When a steel bar is hammered while being magnetized, it requires a higher degree of magnetism; but when a magnet is violently disturbed, as by a fall, it loses a part of its magnetic force. If a bar of soft iron be held in a vertical position, and twisted, it will become feebly but permanently magnetized.



Fig. 220.

II.—TERRESTRIAL MAGNETISM.

325. **The Earth as a Magnet.**—Observations on the direction of the magnetic needle in different parts of the world seem to show that the earth itself is a magnet, the poles of which are near the geographical poles, and its neutral line almost coincident with the equator.

While we speak of that extremity of the needle which points to the north as its north pole, it is really the south or austral pole of the magnet, and is so named by the French. The English sometimes call it the *marked end* of the magnet; by some it is designated the *north-pointing pole.*

326. The **declination of the magnetic needle** is the angle which the direction of the needle makes, at any place, with the meridian, or north and south line.

As the magnetic poles of the earth do not coincide with the geographical poles, the direction of the needle which is toward the former, must vary more or less from the north according to the situation of the place. At present, the declination of the needle is west in Europe and Africa, and east in Asia and in most parts of America. It undergoes variations at different times, even in the same place.

In certain parts of the earth, the direction of the needle is directly north and south. The irregularly curved line drawn through these places is called a *line of no variation*, or *agonic* line. Lines connecting those points on the earth's surface where the declination is the same are called *isogonic lines;* and maps showing the direction of these lines are called *declination maps.* Owing to the variation of the declination, these maps require correction from time to time. The annual variation of the declination was discovered by Cassini in 1780.

The declination is subject to annual and diurnal variations, besides acci-

dental or occasional changes due to magnetic storms, earthquakes, and volcanic eruptions. In polar regions, the needle sometimes oscillates several degrees, especially as a presage of the aurora borealis.

327. **Mariner's Compass.**—The most important instrument containing an application of the directive property of the magnetic needle, is the *mariner's compass*, used in guiding the course of a ship at sea.



Fig. 227.

This instrument is represented in Fig. 227. It consists of a cylindrical case, B B', which is supported on two concentric rings to keep the instrument horizontal. Of these one, attached to the case, moves on the axis $d\,x$; and the other, A B, moves in the support P Q on the axis $m\,n$, at right angles with the first. The

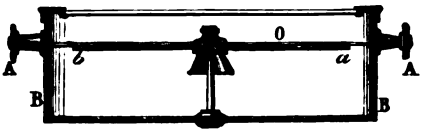


Fig. 228.

needle is a magnetic bar, $a\,b$ (shown in Fig. 228, which represents a vertical section of the compass). This rests on a pivot fixed to the bottom of the box, and capped with agate; and moves with a disc of mica, on which are traced the points of the compass, N corresponding to the position of the needle and marked by a star. The direction of the vessel must coincide with the sight-vane passing through a line, d, marked on the inside of the box (sometimes called *lubber's point*).

328. **Inclination or Dip of the Magnetic Needle.**—The position of the needle, when suspended so as to move freely, is not par-

allel with the plane of the horizon, but makes with it an angle, which varies at different places. This is called the *inclination or dip of the needle.*

In the northern hemisphere, the north pole of the needle dips downward; in the southern hemisphere, the south pole. The dip is greatest in the polar regions, and diminishes toward the equator, where it is zero, or nearly so. The circle on the earth drawn through all those places at which there is no dip, is the *magnetic equator*, or *aclinic line.* Lines connecting places in which there is the same angle of inclination are called *isoclinic lines.* The inclination, like the declination, is subject to constant change.

329. An **astatic needle** is one so placed that it cannot be affected by the magnetism of the earth.

A needle moving on an axis in the plane of the magnetic meridian and parallel to the inclination would be *astatic.* Two needles joined parallel to each other, with the poles in contrary directions, as shown in Fig. 229, form an *astatic system.*

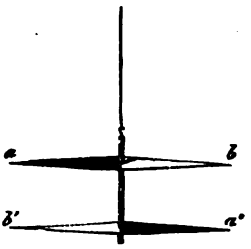


Fig. 229.

The *intensity of terrestrial magnetism* varies in different places, and in the same place at different times. The total magnetic action of the earth has been estimated to be equal, for every cubic yard, to that of eight bar magnets, each weighing a pound.

The magnetic intensity increases as we go toward the poles. Humboldt found the point of least intensity on the magnetic equator in northern Peru. Compared with this, at Naples, in lat. 40° 50′ N., the magnetic intensity is 1.274; and at Spitzbergen, in lat. 79° 40′ N., it is 1.567.

Lines on the earth's surface drawn through places where the magnetic intensity is the same, are called *isodynamic lines.* These lines are not parallel to the magnetic equator, but very nearly follow the direction of the isothermal lines.

Magnetic phenomena have, for several years, been carefully observed at special observatories located in different parts of the earth. From these observations, it appears that the earth's magnetism undergoes constant changes or fluctuations, which are due to the operation of general laws as yet but imperfectly understood.

Magnetic storms have been shown to be periodical in their occurrence; and a careful comparison of magnetic and astronomical observations seem to prove that the period of greatest disturbance in the terrestrial magnetism coincides with the period of greatest apparent agitation of the sun's atmosphere, as shown by the number, size, and frequency of the solar spots. At the observatory at Kew, a luminous mass was seen to shoot across a vast sun-spot, at the same time that the magnetic needle indicated powerful disturbance, simultaneous with which there occurred one of the most violent magnetic storms ever known.

The *aurora borealis* is most generally seen during a magnetic storm; indeed, no great display of the aurora can occur unless as the result of violent and extensive magnetic disturbance. (See Art. 411.)

SYNOPSIS FOR REVIEW.

MAGNETISM.

I.—PROPERTIES OF MAGNETS.

1. *Magnets and Magnetism.*—Lodestone.
 1. Artificial magnet.
 2. Poles.—Neutral line.
 3. Law of attraction.
 4. How illustrated.
2. *Magnetic Fluids.*
3. *Magnetic Substances.*
4. *Magnetic Induction.*
 Temporary and permanent magnets.
5. *Law of Magnetic Attraction:*
 Illustration: 1. By the torsion balance, 2. By magnetic curves.
6. *Magnetic Battery:*
 1. Plate battery.
 2. Horse-shoe battery.
 3. Armatures, or keepers.
7. *Effect of Temperature on Magnets:*
8. *Magnetization:* 1. By single touch. 2. By separate touch. 3. By double touch.
 Effect of hammering and of disturbance.

II.—TERRESTRIAL MAGNETISM.

1. *The Earth as a Magnet:*
 1. Its magnetic polarity.
 2. Location and designation of magnetic poles.
2. *Declination of the Magnetic Needle:*
 1. Cause.
 2. Line of no variation, or agonic line.
 3. Isogonic lines.
 4. Variation of declination.
3. *Mariner's Compass:*
 Construction and use.
4. *Inclination or Dip of the Magnetic Needle:*
 1. Cause.
 2. Direction in N. and S. hemispheres.
 3. Aclinic line, or magnetic equator.
 4. Isoclinic lines.
5. *Astatic Needle:*
 Astatic system.
6. *Intensity of Terrestrial Magnetism:*
 1. Variation.
 2. Total magnetic action of the earth.
 3. Magnetic storms.
 4. Aurora borealis.

CHAPTER IX.

FRICTIONAL ELECTRICITY.

I.—PHENOMENA AND LAWS OF ELECTRICAL ACTION.

330. **Nature of Electricity.**—Electricity is a powerful physical agent, the existence of which is made known chiefly by attraction and repulsion, but also by luminous and heating effects, and various other phenomena. Its action is excited by friction, pressure, chemical operations, heat, and magnetism. When excited by friction, it is called *frictional electricity*.

When a glass rod or a stick of sealing-wax is held in the hand, and rubbed with a piece of flannel, the parts rubbed will attract light substances, such as fibers of silk or wool, feathers, bran, gold-leaf, or small pieces of paper; but these, after coming in contact with the excited body, will be repelled.

The name *electricity* is derived from *electron*, the Greek word for amber; as it was discovered by Thales, in the middle of the sixth century, B.C., that amber when rubbed with silk acquires the property of attracting light substances. About twenty-two centuries afterward, during the reign of Queen Elizabeth, Dr. Gilbert showed that this property exists not only in amber but in sulphur, wax, glass, and other bodies. From the latter part of the eighteenth, and during the present, century, the researches have been made from which our present extensive knowledge of the action and effects of this wonderful agent has been deduced.

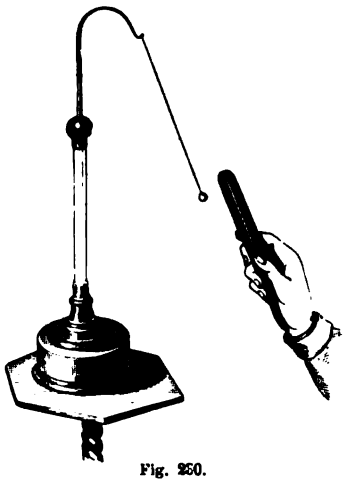


Fig. 230.

331. **Electroscopes** are instruments used to ascertain whether a body is electrified or not.

The simplest of these is the *electric pendulum* (Fig. 230), which consists of a

pith-ball suspended by a silk thread from a glass support. If an electrified body is brought near the pith-ball, the latter is attracted, and after contact repelled.

A solid body may be electrified by friction with a liquid, or with a gas. If a small quantity of mercury be shaken rapidly in an exhausted glass tube, the latter will become luminous. Some substances, as the metals, cannot be excited by friction when held in the hand, because the electricity is conducted from them as fast as it is produced.

332. **Conductors and Non-Conductors.**—Bodies through which electricity passes freely are called *conductors;* those which resist its passage are called *non-conductors.*

When a dry glass rod or a stick of sealing-wax is rubbed at one end, it becomes electrified at that part only, showing that the electricity excited does not pass from one end to the other. These substances are *non-conductors.* On the contrary, when electricity is excited in one part of a metal, it spreads over its whole surface, because metals are good *conductors.* All substances, however, conduct electricity to some extent; and all make more or less resistance to its passage. Hence there are no absolute conductors or non-conductors.

The following substances may be classed as *conductors:* Metals, charcoal (well burned), graphite (plumbago, or black lead), acids, aqueous solutions, water, snow, vegetables, animals, linen, cotton.

The following are *non-conductors:* Ice (at −25° C.), lime, India rubber, air (and all dry gases), dry paper, silk, precious stones, glass, wax, sulphur, resins, amber, shellac.

The following are *semi-conductors:* Alcohol and ether, powdered glass, flour of sulphur, dry wood, paper, ice at zero.

333. **Insulation.**—When a body rests on a non-conducting substance, as glass or resin, or is suspended by a silk thread, so as to retain the electricity it acquires, it is said to be *insulated.* Hence, non-conducting substances are called *insulators.*

No substances are *perfect* insulators, since all electrified bodies lose their electricity with greater or less rapidity through the bodies with which they are in contact. Dry air is a good insulator, but moist air a conductor; hence, in electrical experiments, the insulating substances must be rubbed perfectly dry.

Metals when insulated can be electrified by friction. Thus, if a brass tube is held by a glass handle and rubbed with silk or flannel, it becomes charged with electricity, as can be shown by test with the pith-ball of the electric pendulum (Fig. 230). When the metal is held in the hand, the electricity passes through the body of the person holding it, to the ground.

334. There seem to be two kinds of electricity—that excited in glass, called *vitreous electricity;* and that excited in resinous substances, such as sealing-wax or shellac, called *resinous electricity.*

If an electrified glass rod be brought near an electrical pendulum, it will

attract the pith-ball, and after contact repel it, the ball becoming electrified. Now if an electrified stick of sealing-wax be brought near the ball, it will attract it, and after contact repel it; thus proving the following law:

335. When bodies are charged with the same electricity, they repel each other; but when charged with opposite electricities, they attract each other.

The electrical phenomena are accounted for on the theory proposed by Dr. Franklin, that electricity is a subtle fluid pervading all matter, and when in the natural state in equilibrium; and that by friction some bodies obtain an additional quantity, and become *positively electrified;* while others, losing a part by friction, are *negatively electrified.* Hence the terms *positive* and *negative electricity*, represented by the signs + and −, the former corresponding to vitreous, and the latter to resinous electricity.

Symmer's theory assumes that the electric fluid is formed by the union of two fluids—the positive and the negative; which in the natural state neutralize each other, but are separated by friction; and that the electrical condition of a body depends on which one is in excess.

336. When two bodies are rubbed together, one body acquires positive and the other negative electricity.

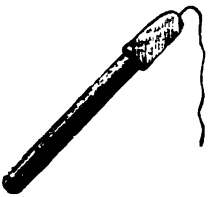


Fig. 231.

To prove this the following experiment was devised by Faraday: A small flannel cap, having a silk thread attached to it (Fig. 231), is fitted on the end of a thick rod of shellac, and rubbed round upon it several times, so as to excite the rod. The cap is then removed by means of the thread (which insulates it); and when presented to a pith-ball positively charged repels it; while the stick of shellac attracts it. This shows that the cap is charged with positive electricity while the shellac acquires negative electricity—and in equal quantities; because, if the rod and cap together are presented to the pith-ball, they neither attract nor repel.

337. The electricity developed by friction depends on both the rubber and the body rubbed.

Thus glass is negatively electrified when rubbed with cat's skin, and positively when rubbed with silk. In the following list the substances are arranged in such an order that each is positively electrified when rubbed with any of those following it, and negatively when rubbed with any of those that precede it:

1. Cat's skin.	5. Glass.	9. Wood.	13. Resin.
2. Flannel.	6. Cotton.	10. Metals.	14. Sulphur.
3. Ivory.	7. Silk.	11. India rubber.	15. Gutta-percha.
4. Rock-crystal.	8. The hand.	12. Sealing-wax.	16. Gun-cotton.

The character of the electricity developed by friction depends also on the direction in which the bodies are rubbed, their relative temperature, and the smoothness of their surfaces. The body of the lower temperature, or smoother

surface, is positively electrified; and if two silk ribbons are rubbed across each other, the one transversely rubbed is negatively charged.

Pressure and cleavage also develop electricity. If a piece of India rubber and a piece of cork be pressed together, the cork will become positively and the India rubber negatively electrified. If a plate of mica be rapidly split in the dark, a phosphorescent light will be observed. Sugar, when broken in the dark, is also seen to emit light from the same cause.

By delicate experiment with a torsion balance, Coulomb discovered the law, that the force of attraction or repulsion between two electrified bodies is inversely in proportion to the square of their distance.

338. **Distribution of Electricity.**—When a body is electrified, the electricity does not penetrate into the interior, but is confined to the surface of the body. Therefore, the distribution of electricity depends not on the mass of the body, but on the extent of its surface.

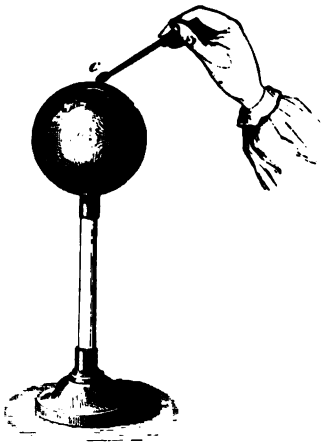


Fig. 232.

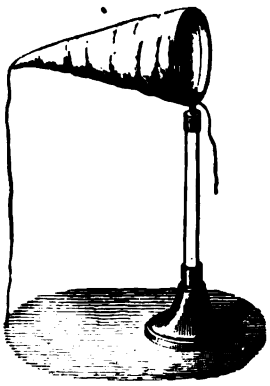


Fig. 233.

This can be shown by the hollow sphere and proof-plane (Fig. 232). A hollow copper sphere, having an orifice at the top, is insulated and charged with electricity. A small disc of copper foil insulated by a thin handle of glass or shellac (called a *proof-plane*) is applied to the internal surface of the sphere, and when tested by the electric pendulum shows no trace of electricity; but if it is applied to the external surface of the sphere, and then tested, it is found to be electrified.

Faraday's experiment ingeniously illustrates this principle. A metal ring with a conical gauze bag is fitted to an insulating stand (Fig. 233). The bag being charged is found by the proof-plane test to be electrified on the outside. It is then turned inside out by means of a silk thread attached to the end and

extending both ways; and the electricity is found on the outer, not the inner surface, showing that it has passed from one to the other.

When an insulated bird-cage is charged with electricity, bodies within the cage are unaffected by it, while the outside gives strong indications of electrical action.

The accumulation of the electricity on the outer surface of bodies is conceived to arise from the repulsion which the particles exert on each other. The electricity is thus forced to the outside, where it is confined by the poorly conducting atmosphere.

339. **Electric Density.**—The quantity of electricity existing at any moment on a given surface is called the *electric density.*

When a metallic sphere is electrified, the electricity is uniformly distributed over its surface, as can be shown by a proof-plane and torsion balance (Fig. 222); but in unsymmetrical figures this is not the case. In the case of a cylinder

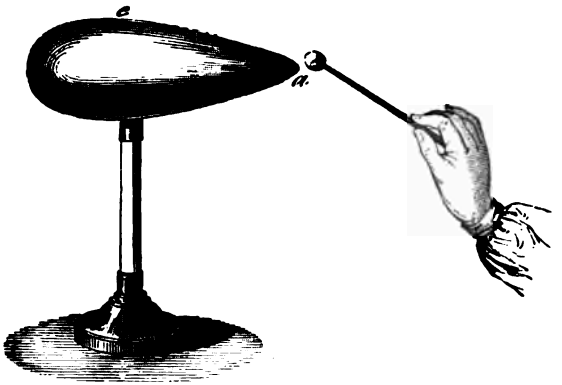


Fig. 234.

with rounded ends, for example, the density would be greatest at the ends and least in the middle portions. If an ellipsoidal body (Fig. 234) be electrified, it will be found that the distribution of electricity is greatest at the point *a*, and least at the middle part *e*.

The electricity accumulates at the most acute points. When the hand is brought near a point on an electrified conductor, a slight wind is felt; and if the electricity is disengaged in the dark, a luminous brush is seen. Hence, to retain electricity all sharp points and edges must be avoided; and the contrary, if the object is to facilitate its outflow. Conductors usually terminate in knobs.

340. **Induction** is the influence which an electrified body exerts over a body placed near it, in charging it with opposite kinds of electricity.

If an insulated brass cylinder, A (Fig. 235), be placed near an insulated con-

ductor, M, charged with positive electricity, free electricity will be developed at each end of the cylinder, negative at the end near M, and positive at the farther end. Thus the cylinder becomes polarized, the two ends being the poles. This will be indicated by the repulsion of the pith-balls suspended by linen threads, as shown in the figure. And if an excited glass rod be held at the one near M, it will be attracted, showing that it is negatively electrified; while, if an excited stick of sealing-wax be used, the pith-ball will be repelled. The same phenomena reversed will be presented by the other pith-ball.

The effects of induction are ascribed to the decomposition of the neutral electricity of the cylinder by the free positive electricity of the conductor, attracting to the end nearest it the opposite electricity, and repelling that of the same kind. Between the two ends, or poles, there is a neutral space.

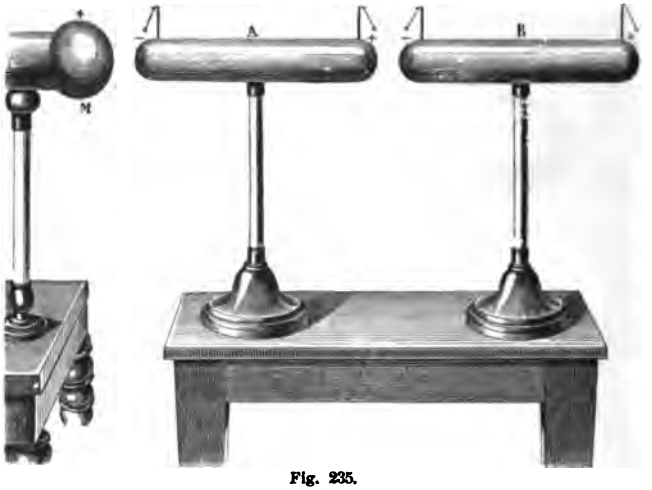


Fig. 235.

When a body is charged by conduction, the charging body loses a part of its electricity; but in induction this is not the case. In conduction the electricity imparted is of the same kind; in induction, of the opposite kind. In conduction, there must be complete insulation; but in induction, every additional charge requires at least a momentary connection with the earth. Thus, when both pith-balls diverge (Fig. 235), if the farther end of the cylinder be connected with the earth, thus allowing the positive electricity to escape, the pith-ball at that end will immediately collapse; while that at the other end continues to diverge, showing that the negative electricity is still supplied.

A body electrified by induction acts in turn on bodies near it, as shown in the cylinder B in Fig. 235, the part near the positive end being negatively electrified, and the other positively.

Faraday showed that electric induction is not really, as it seems, an action at a distance, but that successive layers of the intervening air, or other insulating

substance, become alternately charged with positive and negative electricity. To this he gave the name *dielectric polarization*, and called the varying capacity which bodies possess of transmitting electricity the *inductive power*.

This is manifested by insulating bodies, or *dielectrics*, in different degrees. Thus, if at a certain distance the inductive action of an electrified body upon the electroscope be observed, and a disc of sulphur or shellac be then interposed, other conditions remaining the same, the electric action will be found to be almost doubled; showing that induction takes place twice as effectually through the one dielectric substance as the other.

The inductive capacity of air being represented as 1, resin is 1.76; glass, 1.90; sulphur, 1.93; shellac, 1.95; India rubber, 2.80; gutta-percha, 4.00; and mica, 5.00.

341. **Communication of Electricity at a Distance.**—When bodies at a distance from each other are charged with different kinds of electricity, the immediate passage of one kind to the other is prevented only by the non-conducting air between. Hence, when the density is increased, or the distance diminished, beyond a certain limit, they rush together, producing a spark, and causing a sharp, crackling sound.

When a finger is presented to a strongly electrified conductor, the latter separates the neutral electricity of the body; and the opposite electricities combine with a spark.

342. **Lightning and Thunder.**—*Lightning* is caused by the passage of electricity between a thunder-cloud and the ground, or between two clouds, one being positively and the other negatively electrified by induction. *Thunder* is the violent report which accompanies the discharge, and is caused by the disturbance produced in the air, by the passage of the electricity.

The clouds are generally electrified, either positively or negatively, and when passing over the ground induce in it the contrary kind of electricity. When a thunder-cloud is positively charged, as it generally is, the ground becomes negatively electrified; and when the distance is small enough and the density sufficiently great, a discharge takes place, generally of the positive electricity. Lightning, therefore, usually comes from above; but sometimes it passes from the earth to the cloud, and sometimes from cloud to cloud.*

*Many of the early investigators of electrical phenomena conceived that lightning was kindred with the electric spark; but it was Dr. Franklin who demonstrated their identity, by means of his famous kite experiment—sending up a kite into a thunder-cloud, and drawing the electricity down, by means of the string, to the end of which a key was attached, and to this a silk ribbon in order to insulate it from the hand. Soon there were decisive indications of an electric charge; and placing his knuckle at the key, he produced a succession of strong sparks. It was a dangerous experiment, and subsequently a Russian physicist lost his life by attempting a similar one.

A cloud densely charged with positive electricity affects the electrical condition not only of the part of the earth near to it, but objects on its surface, including living beings. When the discharge takes place, there is an immediate return to the neutral state, which causes a violent concussion that sometimes destroys life. This is called the *return shock*.

II.—ELECTRICAL APPARATUS.

343. **Gold-leaf Electroscope.**—This is an instrument for determining the presence of electricity in a body, and the kind of electricity with which it is charged.

This instrument has, therefore, the same use as the pith-ball pendulum, but is more delicate. It is shown in Fig. 236. Two strips of gold-leaf, *n n*, are attached to the lower end of the metal rod, which passes through an opening in the top of the bell-glass B, and terminates in the knob C. The bell-glass stands on a metal foot, and for more complete insulation is varnished with shellac at the upper part. The air inside is dried by quicklime, and there are within two small metallic columns, *a*, which communicate with the ground, so that should the strips of gold-leaf diverge so far as to come in contact with them, they lose their charge and collapse.



Fig. 236.

When the knob is touched with a body charged with either kind of electricity, the strips of gold-leaf separate; and when an electrified body—a glass rod or a stick of sealing-wax, A—is held near the knob, the latter becomes, by induction, charged with negative or positive electricity; and the strips of gold-leaf, becoming oppositely electrified, are made to diverge.

344. The **electrical machine** is an instrument for the development of electricity. It is constructed in several different forms.

The *plate electrical machine* consists of a circular glass plate, P (Fig. 237), placed on an axis between two wooden supports, and turned by a handle, M. The plate revolves between two sets of *cushions* or *rubbers*, F F, of leather or silk, one set being above the axis and the other below, and so arranged that they may be pressed against the glass as firmly as required. The plate moves between two brass rods shaped like a horse-shoe, and supplied with a number of points on the sides opposite the glass. These rods are fixed to large metallic cylinders, C C, called the prime conductors, which are insulated by being supported on glass feet, and are connected by a rod, *r*.

When the plate is revolved the glass becomes positively and the rubbers negatively electrified; and as the latter are connected with the ground by means of a chain, they constantly lose the negative electricity acquired. The positive electricity of the glass, acting by induction on the conductor, causes negative electricity to collect at the points; and this, after reaching a certain degree of density, passes across to the glass plate, and neutralizes its positive electricity. The con-

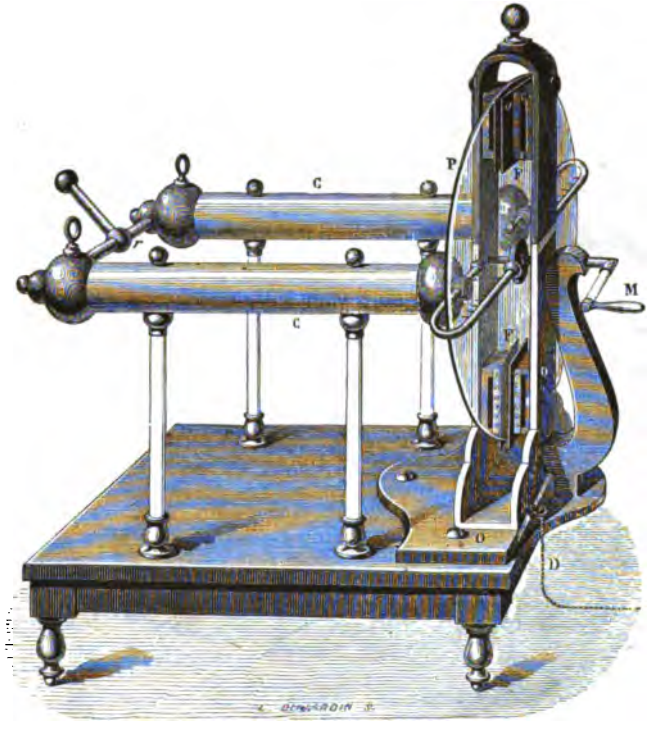


Fig. 237.

ductors thus lose their negative electricity and remain charged with positive electricity. The plate, therefore, gives nothing to the prime conductors, only taking from them their negative electricity. If the hand be brought near the knob of the conductors when charged, a spark follows, which is repeated as often as the plate is turned.

The machine as thus arranged gives only positive electricity; but if the conductor be connected with the ground, and the machine be placed on an insulated table, the positive electricity escapes, and the negative is collected in the supports and on the table. Thus a spark will pass from the supports to the hand when brought near them.

345. When the loss of electricity becomes equal to its production, the limit of the machine is reached. The loss depends on (1) the conducting power of the atmosphere, varying with its moisture; (2) the escape of electricity through the supports; and (3) the reunion of the electricities of the rubbers and the glass.

When the rotation of the plate reaches a certain degree of rapidity, the charge attains a point at which it overcomes the resistance presented by the non-conducting property of the glass, when the two electricities separated on the rubbers and the glass partly recombine; and the charge then remains constant.

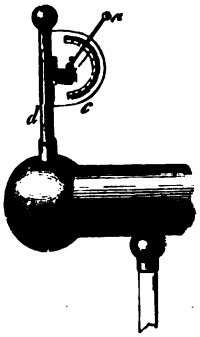


Fig. 238.

346. The **electrometer** is a contrivance used to measure the degree of the charge.

It consists of a pith-ball pendulum and scale, applied to a wooden rod, *d* (Fig. 238), which is attached to the conductor of the machine. As the charge is increased, the pendulum rises, and acts as an index on the scale.

347. The **cylinder machine,** in which a glass cylinder is used instead of a plate, is well adapted to develop either kind of electricity.

In Nairne's machine (Fig. 239) the cylinder is rubbed by only one cushion, C, which is made of leather stuffed with horse-hair, and screwed to an insulated conductor, A. On the opposite side of the cylinder there is a similar insulated

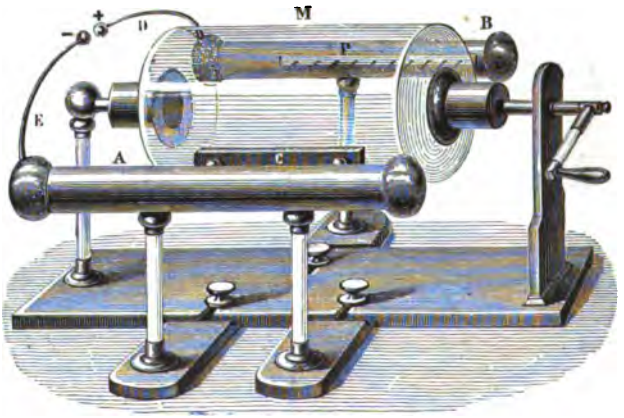


Fig. 239.

conductor, B, which has a series of points next the glass. To the lower part of the cushion there is attached a piece of oiled silk, extending over the cylinder. (This is not shown in the figure.) When the cylinder is turned, A becomes

charged with negative electricity, and B with positive electricity by the loss of its negative from the points P. The two opposite electricities now unite by a succession of sparks across D and E. If use is to be made of the electricity, either the rubber or the prime conductor must be connected with the ground. In the former case, positive electricity is obtained; in the latter, negative.

348. **Holtz's electrical machine,** which acts not by friction but by induction, is a far more effective instrument in developing electricity.

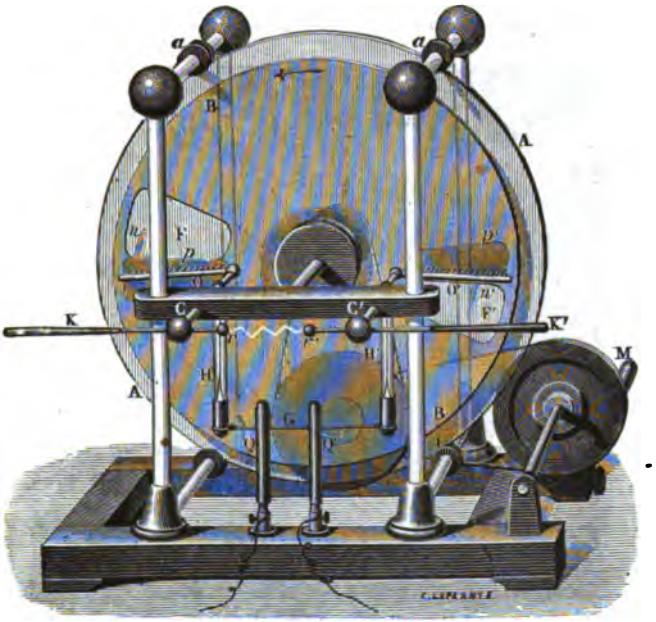


Fig. 240.

This instrument is represented in Fig. 240. It consists of two thin circular plates of glass, about one-eighth of an inch apart, the larger one, A A, being fixed by means of the four wooden rollers *a* resting on glass axles and feet. The other, B B, about two inches in diameter smaller than A A, turns on a horizontal glass axle, by means of the winch M and a combination of wheels. In the plate A are two large openings, F and F', along the edges of which bands of paper, *p* and *p'*, are glued, and strips of cardboard, *n* and *n'*. The papers *p*, *p'* constitute the *armatures*, which are covered with shellac varnish, as are also the tongues and the plates. In front of the plate B, at the height of the armatures, are two brass combs, O and O', which are attached to two brass conductors, C and C', having on their front ends large brass knobs through which pass brass rods ter-

minating in the small knobs r and r', and provided with vulcanite handles, K and K. These rods can be moved together or apart. The plate is moved, as indicated by the arrows, toward the points n, n'.

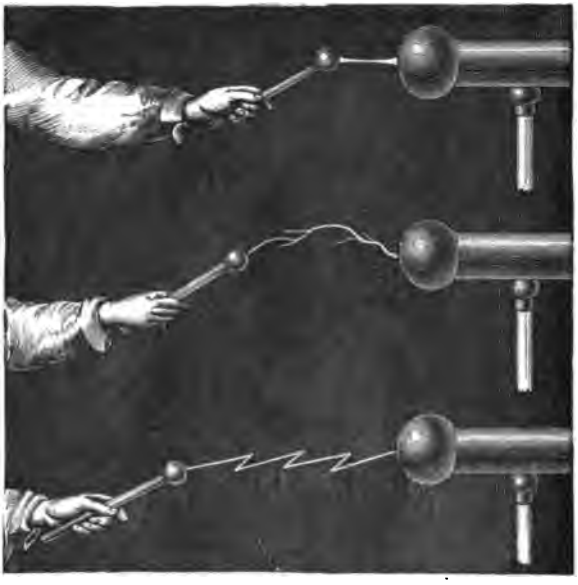
To work the machine, the knobs r, r' are brought together, and a plate of vulcanite, electrically charged, is brought near to one of the armatures, as p; the plate is then turned for a few seconds, and the two knobs gradually separated. A crackling ensues, and sparks pass across the interval.

The action is as follows: the vulcanite being charged with negative electricity, withdraws the positive electricity of the armature, and charges it negatively. The armature, acting by induction through the plate B as it turns on the conductors O C and O′ C′, attracts through the comb O the positive electricity

Fig. 241.

Fig. 242.

Fig. 243.



which collects on the front face of the movable plate; while negative electricity, repelled on the comb O′, collects on the front face of the plate B. Hence, at the end of half a turn, the lower half of the plate is positively electrified, and the upper surface negatively. But the two opposite electricities above and below F′ decompose the electricity of the armature p' n', the part p' being positively electrified, while the point n' discharges negative electricity. As the plate is turned, a similar effect is produced on n; and thus a constant supply of electricity is kept up. Very powerful effects can be produced by this machine.

Electricity is also developed by the escape of steam through small orifices, being caused by the friction of the globules of water against the jet. On this principle is constructed *Armstrong's hydro-electric machine.*

ELECTRICAL EXPERIMENTS.

349. **Electric Spark.**—When the hand, or any other conducting substance, is held near the charged conductor of an electrical machine, a spark is produced. This spark assumes different forms.

When it strikes at a short distance, it is rectilinear (Fig. 241); beyond two or three inches, it takes the form of an irregular branching curve (Fig. 242); and if very powerful, assumes a zig-zag shape (Fig. 243).

A spark may be taken from the human body by the aid of an insulating stool, that is, a stool provided with glass legs. A person standing on this and touching the conductor becomes charged; the hair diverges, as the separate hairs are similarly electrified, and consequently repel each other—and a spark passes from any part of the body to a conducting substance.

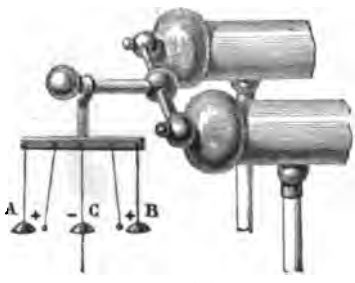


Fig. 244.

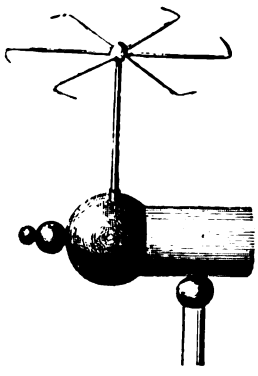


Fig. 245.

350. The **electrical chimes** consist of three bells suspended to a horizontal metal rod.

This is shown in Fig. 244. A and B are positively electrified, being connected by wire with the conductor; but the middle bell C is suspended by a silk thread, and therefore insulated. Between the bells are copper balls, which are alternately attracted and repelled by the bells.

351. The **electrical whirl or vane** consists of several wires with points bent in the same direction and fixed in a central cap, which rotates on a pivot.

As the machine (Fig. 245) is worked the vane revolves rapidly in a direction opposite to that of the points. This is due to the repulsion between the electricity of the points and that which the adjacent air receives from them by conduction. The electricity collecting on the points passes into the air, and thus imparting a

charge of electricity, repels this electricity, while it is itself repelled. In water, which is a good conductor, the vane ceases to rotate.

III.—ACCUMULATION AND CONDENSATION OF ELECTRICITY.

352. The **electrophorus** is a simple contrivance for collecting and preserving electricity.

It consists of a *cake* of resin, B (Fig. 246), about 12 inches in diameter and an inch thick, placed on a metallic surface, or fitting in a wooden mold lined



Fig. 246.



Fig. 247.

with tin-foil, which is called the *form*. A metal disc, A, with a glass handle serves as a *cover*. To use the apparatus, warm all parts of it and place the cake in the form; then charge the cake by striking it briskly with a piece of silk or with cat-skin, and apply the cover. The negative electricity of the cake polarizes the cover, attracting positive electricity to the under surface and negative to the upper. Touch the upper surface (Fig. 247) and the negative electricity will pass off, leaving the cover charged with positive electricity, held by the negative influence of the cake. When the cover is raised by its insulating handle, it may be discharged by touching it with the finger or any conducting substance.

Instead of resin, gutta-percha or vulcanite may be employed, or glass; but, if the latter be used, the electricities in the cover are reversed. The *electrophorus* may for many simple experiments take the place of the machine, of which, in a certain degree, it is the type.

353. A **condenser** is an apparatus for collecting a large quantity of electricity on a comparatively small surface. It consists essentially

of two insulated conductors separated by a non-conductor, acting on the principle of induction.

Epinus's condenser, represented in Fig. 248, consists of two circular brass plates, A and B, with a sheet of glass, C, between them. The plates are insu-

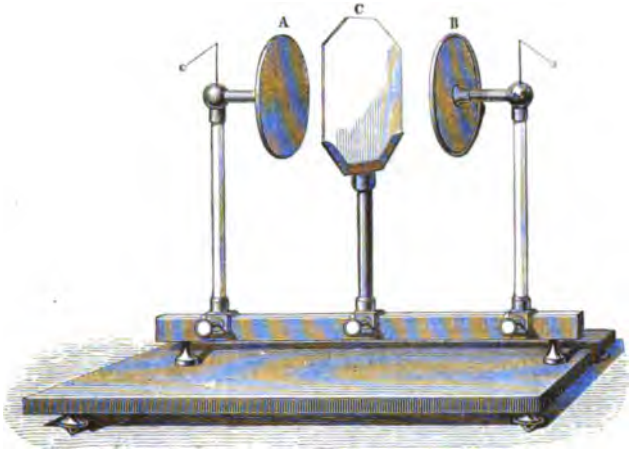


Fig. 248.

lated, resting on glass legs, movable along a support, and each has a pith-ball pendulum attached to it. To accumulate electricity, the plates are placed in contact with the glass, and one is connected with the conductor of an electrical machine, the other being connected with the ground.

The principle of its action may be thus explained: B (Fig. 249) being charged with positive electricity by the machine, causes an accumulation of

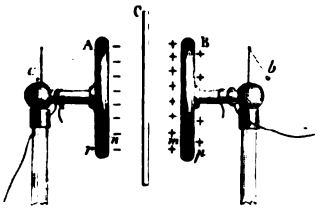


Fig. 249.

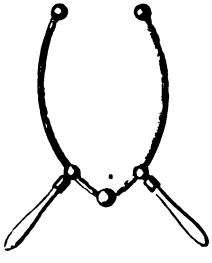


Fig. 250

negative electricity in A on the surface n, the positive on r passing to the ground. But the negative electricity upon n reacts on the surface m and induces in it an excess of positive electricity, diminishing that of p, which is thus able to receive

more from the machine. When there is an equilibrium between the machine and p, no more can be received, and the condenser is fully charged. Connection with the ground is then broken.

An instantaneous discharge can be effected by means of the *discharging rod* (Fig. 250). This consists of two bent brass rods joined by a hinge, and provided with glass handles. One of the knobs is pressed against one plate of the condenser, and the other knob brought near the other. The two opposite electricities are thus suddenly recombined and the equilibrium restored.



Fig. 251.

354. **Leyden Jar.**—The *Leyden jar*, which received its name from the place where it was invented, is a kind of condenser. It consists of a glass jar, the interior of which is either coated with tin-foil or filled with thin leaves of copper or gold-leaf; and the outside also coated with tin-foil except at the upper part. The mouth is closed with a cork, through which a brass rod is passed, that terminates at one end in a knob, and communicates with the metal coating within.



Fig. 252.

Like the condenser described (Art. 352), the jar is charged by connecting either the internal or external coating with the machine and the other with the ground. When it is held in the hand by the external coating (Fig. 251) and the knob presented to the positive conductor, positive electricity is accumulated on the inner and negative on the outer coating; but if the jar is held by the knob, and the external coating presented to the conductor, the reverse takes place. The positive charge acting inductively across the dielectric glass, decomposes the electricity of the outer coating, attracting the negative and repelling the positive, the latter passing off by the hand to the ground. Thus the two coatings act like the plates A and B (Fig. 249).

The Leyden jar may be instantaneously discharged by grasping the outside coating with one hand, and connecting the two coatings by means of the discharging rod (Fig. 252). A smart shock will be felt, unless care be taken to touch the external coating *first* with the discharger. It may be discharged slowly by placing it on an insulated plate, and touching, either with the hand or with a metallic conductor, first the inner and then the outer coating. The discharge then takes place with a succession of slight sparks.

The *jar with movable coatings*, A (Fig. 253), is used to show that the electricity collected in the Leyden jar is accumulated chiefly on the surfaces of the glass. For if the jar A be charged, placed on an insulating plate, and then taken apart; and the outside coating, C, as well as the inside part, D, be discharged; and then if they be put together again, a shock may be taken from it nearly as strong as before the coatings were removed. The coatings, therefore, merely perform the office of conductors, and distribute the electricity over the surface of the glass.

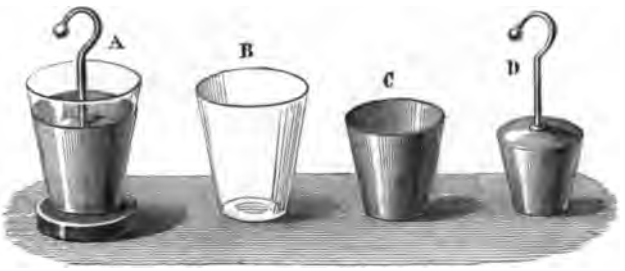


Fig. 253.

355. An **electric battery** consists of a number of Leyden jars, having their internal and external coatings respectively connected with one another, so that they may act as a single large jar.

The larger and thinner the jar, the more powerful the charge of which it is capable; but large jars are unwieldy and thin ones liable to break; and, moreover, when the glass is very thin, the electricities are apt to discharge themselves through it. Hence the use of the battery (Fig. 254). The jars are placed in a box lined on the bottom with tin-foil, which is connected with two metal handles in the sides. The inner coatings are connected with each by metallic rods, and the outer coatings connect with the ground by means of a chain fixed to the handles. The battery is charged by placing the inner coatings in contact with the conductor of an electrical machine, and discharged by connecting the coatings, in the same manner as a single jar.

In experimenting with large batteries great caution is needed to avoid serious or even fatal accidents. In such experiments, the *universal discharger* is employed, which consists of a wooden stand on which there are two glass pillars supporting two brass rods turning in universal joints and terminating in knobs. Between these pillars is a small ivory table, on which is placed the ob-

ject to receive the charge. The two knobs being directed toward the object on the table, one of them is connected with the outer coating of the battery, and the other with the inner by means of the discharging rod A violent shock is the result, the charge passing through the object.

356. **Electric Discharge.**—The *work* required to discharge a Leyden jar, or battery, consumes a certain amount of force, which, on the principle of the conservation of energy, reappears when the discharge is made. This is manifested in a spark, or in the heating action exhibited. The effects of the discharge are *luminous, mechanical, physiological, chemical,* or *magnetic.*



Fig. 254.

The amount of work required to be done in order to overcome the electrical force—attraction or repulsion—is called the *electrical potential.* Thus, the potential of a small metal sphere charged with positive electricity at an infinite distance from a large sphere similarly charged, is *zero,* and increases as the distance diminishes, because this cannot be done without overcoming the repulsive force of the opposite electricities. The standard electrical potential is that of the earth, which is assumed to be zero. If the potential of a body is higher than that of the earth, it is said to be positive; if lower, negative. When, generally, a current of electricity is flowing from one body to another, the former is said to have a higher potential than the latter.

The *luminous effects* of the electric discharge are of great variety. The spark is of different colors, according to the conducting bodies. Between two charcoal points it is yellow; between two balls of silvered copper, green; between knobs of wood or ivory, it is crimson. In air and in oxygen gas, it is white and brill-

iant; in rarefied air and in hydrogen, it is reddish; and in a vacuum, it is violet. In nitrogen gas it is blue or purple, and accompanied by a peculiar sound.

Brush Discharge.—When the electricity passes from the conductor in an uninterrupted flow, the light emitted assumes the form of a brush, or luminous cone, having its apex at the conductor. There is, also, a peculiar hissing sound, instead of the crackling of the spark. Its size and color depend upon the nature and form of the conductor.



Fig. 255.

The luminous effects in rarefied air can be shown by means of an apparatus called the *electric egg* (Fig. 255), which consists of an egg-shaped glass vessel with a metal cap at each end, the lower one being furnished with stop-cock, so that it may be screwed into an air-pump, and the upper one moving up and down in a leather stuffing-box. When the vacuum is formed, the upper cap is connected with the conductor of an electrical machine, and as the electricity flows in, a violet light fills the glass vessel, which on the admission of the air changes to a brilliant white light.

The *luminous tube* (Fig. 256) is a glass tube about three feet in length, round which are arranged in a spiral form a series of lozenge-shaped pieces of tin-foil, with very small spaces between them. The spiral is connected with the cap and brass hook at each end. When the tube is held in the hand and the hook presented to the conductor, a brilliant luminous appearance is presented.

The *luminous pane* is a square of common glass on which is fixed a narrow strip of tin-foil, in parallel folds. Spaces are cut out of this to represent any figure, for example, a portico. The pane being fixed between insulated supports,



Fig. 256.

and the upper part connected with the conductor, while the lower part connects with the ground, a spark appears at each space in the tin-foil, and the figure is presented in luminous flashes (Fig. 257).

The *heating effects* of the electric discharge are shown in various ways. When it passes through alcohol or ether, it inflames them; coal gas may be ignited by the electric spark; and when a battery is discharged through an iron

or steel wire, the latter becomes highly heated, sometimes incandescent; and is melted by a very powerful discharge.

The *mechanical effects* are shown in the action of a discharge on badly conducting substances. Glass is perforated, wood and stones fractured, and substances of great tenacity torn to pieces. The perforation of glass may be effected in the following manner: Place the glass, A (Fig. 258), to be pierced on a glass support containing a metal point. Near the upper surface of the glass arrange a second point, B, so that it may receive the charge from a Leyden jar or battery, and the passage of the electricity from point to point will perforate the glass.



Fig. 257.

Physiological Effects.—When the outer coating of a charged Leyden jar is grasped with one hand, and the knob connecting with the inner coating is touched by the other, a shock is felt more or less violent according to the size of the jar and the fullness of the charge. A large number of persons may simultaneously receive the charge by holding one another's hands, the person at one end touching the outer coating, and the one at the other touching the knob. The Abbé Nollet, in this way, sent an electric charge through an entire regiment of soldiers, all receiving a violent shock in the arms and shoulders. With powerful charges the organic tissues are destroyed. Dr. Priestley killed rats with batteries having seven square feet of coated surface, and cats with those of 4½ square yards of coating.

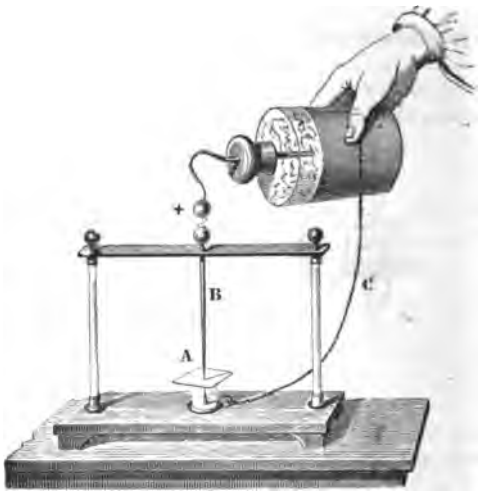


Fig. 258.

The *chemical effects* are shown in the decomposition and recomposition of substances. The electric discharge can be employed so as to decompose water, for example, as well as sulphuretted hydrogen and ammonia.

The *electric pistol* affords another illustration. A detonating mixture, of two parts of hydrogen and one of oxygen, is put into a brass vessel, D (Fig. 259), having a glass tube in the side, into which fits a metal rod, having a knob at each end, A being the one outside. When A is held near a conductor, it becomes negatively electrified by induction, while the inside knob is positively electrified. A spark passes from each, that within causing the combination of the oxygen and hydrogen, thus forming water. This is converted into steam by the heat produced, and the cork closing the vessel is forced out with an explosion.

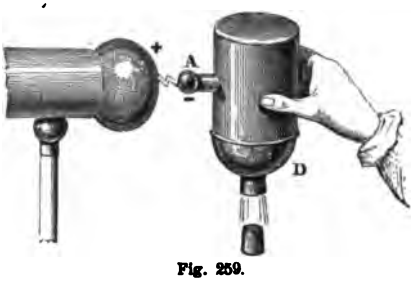


Fig. 259.

Magnetic Effects.—A steel wire, laid perpendicularly to the conducting wire, may be magnetized by the discharge of a large Leyden jar; and a moderate discharge will magnetize a steel bar or needle when placed inside a tube on which is coiled a fine insulated copper wire. The electric current passing through this wire magnetizes the bar. The magnetic needle may also be deflected by the electric current.

357. It has been shown by very delicate experiments upon the electric spark that the discharge is not instantaneous, but occupies an exceedingly small portion of time.

Such experiments have been made by the distinguished electrician Wheatstone, by means of a rotating mirror; and the results showed that the duration of the spark was one twenty-four-thousandth part of a second. Other experiments with more delicate apparatus reduce this time considerably—to between 23 and 46 ten-millionths of a second, depending upon the number of jars in the battery.

358. **Velocity of Electricity.**—Electricity travels with a velocity somewhat greater than that of light.

Wheatstone's experiments resulted in showing a velocity of 288,000 miles in a second; but this, if correct, is true only of frictional electricity, that of dynamical electricity being much less. The velocity of a current of electricity passing through a wire without resistance, being like that of a wave on a stretched string, has been ascertained by Kirchhoff to be about 193,000 miles a second, or a little greater than that of light in a vacuum.

Telegraph wires induce opposite electricities in the surrounding media, and thus give rise to a resistance which diminishes the velocity; and in wires insulated in water, the velocity is less than in air. The passage of a current through submarine telegraphic cables is, therefore, comparatively slow.

SYNOPSIS FOR REVIEW.

FRICTIONAL ELECTRICITY.

I.—PHENOMENA AND LAWS OF ELECTRICAL ACTION.

1. *Nature of Electricity.*
 Origin of name.—Simplest phenomena.
2. *Electroscopes.*
3. *Conductors and Non-conductors.*
4. *Insulation and Insulators.*
5. *Positive and Negative Electricity.*—Vitreous and resinous electricity.
6. *Theories:*
 1. Dr. Franklin's.
 2. Symmer's.
7. *Law of Electrical Attraction and Repulsion.*
8. *Distribution of Electricity.*—On what dependent.
9. *Electric Density.*—Where greatest.
10. *Induction:*
 1. Phenomena, and how shown.
 2. Effects—to what ascribed.—Polarity.
 3. Dielectric polarization.—Dielectrics.
 4. Communication of electricity at a distance.—Lightning and thunder.—Cause.

II.—ELECTRICAL APPARATUS.

1. *Gold-leaf Electroscope.*
2. *Electrical Machine:*
 1. Plate electrical machine.
 2. Cylinder machine.
 3. Holtz's electrical machine.
3. *Electrometer.*
4. *Electrical Experiments:*
 1. Electric spark.
 2. Electrical chimes.
 3. Electrical whirl or vane.

III.—ACCUMULATION AND CONDENSATION OF ELECTRICITY.

1. *Electrophorus.*
2. *Condenser.*—Epinus's condenser.
 Discharging rod.
3. *Leyden Jar.*
 Jar with movable coatings.
4. *Electric Battery.*
5. *Electric Discharge.*
 1. Luminous effects:
 1. Brush discharge.
 2. Luminous tube.
 3. Luminous pane.
 2. Heating
 3. Mechanical
 4. Physiological
 5. Chemical
 6. Magnetic

 } effects.
6. *Electrical Potential.*
7. *Duration of the Electric Spark.*
8. *Velocity of Electricity.*

APPLICATION OF PRINCIPLES.

MAGNETISM.—1. How are the phenomena of magnetism explained? 2. What change takes place in a body when it becomes a magnet? 3. When a magnet is broken in halves, why does each half become a magnet? 4. How is a piece of soft iron changed into a magnet? 5. How are the magnetic curves rendered visible? 6. What do these curves show? 7. How may the law of magnetic attraction and repulsion be demonstrated by means of the torsion balance? 8. Why is the horse-shoe battery best adapted to support a weight? 9. Why do armatures preserve the strength of magnets?

10. What is the effect of heat upon magnets? 11. How may substances be magnetized? 12. Why is the earth thought to be a magnet? 13. Which is the north pole of the needle? 14. What causes the declination of the magnetic needle? 15. On what principle is the mariner's compass constructed? 16. What causes the inclination of the needle? 17. On what principle is an astatic system constructed? 18. What does a display of the aurora borealis indicate? 19. Why is a relation supposed to exist between magnetic storms on the earth and the spots on the sun's disc? 20. How can the north and south poles of a bar magnet be distinguished? 21. Does the magnetic meridian ever coincide with the geographical meridian?

FRICTIONAL ELECTRICITY.—1. What is the use of the electric pendulum? 2. What is the principle of its action? 3. Why cannot a metallic rod held in the hand be electrified? 4. Why is light produced in a glass tube when mercury is shaken in it? 5. Why is a stick of sealing-wax rubbed at one end electrified only at that end? 6. Why must substances used for insulation be rubbed perfectly dry? 7. How can a brass tube be electrified by friction? 8. How can it be shown that bodies similarly electrified repel each other? 9. How does the theory of two fluids explain electrical phenomena? 10. With what should glass be rubbed to become positively electrified? Why?

11. With what should ivory be rubbed to be positively electrified? 12. Sulphur? 13. Why? 14. If a piece of cork and a piece of India rubber be rubbed together, what electricity will be developed in each? 15. Why does loaf-sugar emit light when it is broken in the dark? 16. Why does electricity accumulate on the outer surface of a body? 17. When a sphere is electrified, how is the electricity distributed? 18. How in the case of a cylinder? 19. How in an ellipsoid? 20. How, generally, in bodies of an unsymmetrical form?

21. How do sharp points or edges affect the flow of electricity? 22. How is induction caused? 23. How does induction differ from conduction? 24. What is dielectric polarization? 25. What bodies are dielectrics? 26. How is the electric spark produced? 27. How are lightning and thunder caused? 28. What causes the return shock? 29. On what principle is the gold-leaf electrometer constructed? 30. What limits the production of electricity by the electrical machine?

31. How is electricity accumulated? 32. Explain the action of the Leyden jar? 33. How is it discharged? 34. What different effects are produced by an electric discharge? 35. What is meant by electrical potential? 36. What is the difference between a high and a low potential? 37. In what manner may Leyden jars be connected so as to form a battery? 38. What principles are applied in this? 39. On what principle is the universal discharger based? 40. The luminous pane? 41. The electric pistol? 42. How may glass be perforated by the electric discharge? 43. How may a steel wire or bar be magnetized by electricity?

CHAPTER X.

GALVANIC OR DYNAMICAL ELECTRICITY.

I.—GALVANIC OR VOLTAIC BATTERIES.

359. **Galvanic or dynamical electricity** is that which is produced by the chemical action of one substance upon another. It is also known as *voltaic electricity*. The department of physics which treats of dynamical electricity is sometimes called *galvanism*.

It derives this name from Galvani, a professor of anatomy in Bologna, Italy, who first observed the phenomenon of chemical electric action, in 1790. While

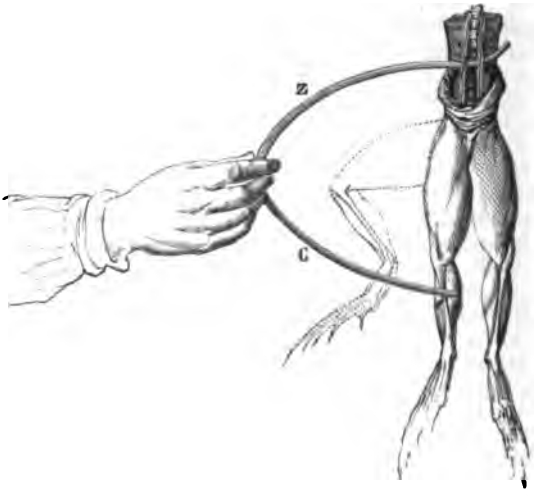


Fig. 260.

investigating the physiological effects of electricity, he noticed that when the back nerves of a dead frog were connected, by a metal conductor, with the muscles of the legs, the latter were drawn up. The experiment is shown in Fig. 260. The metal conductor is composed of zinc, Z, and copper, C, the zinc end being thrust

between the nerves of the vertebral column, while the copper end touches one of the muscles of the leg, which at once is drawn into the position indicated. Galvani attributed the phenomenon to an electricity existing in the body of the animal, which he called the *vital fluid*, conceiving that it passed by the metal conductor from the nerves to the muscles, and thus caused their contraction, the former being positively and the latter negatively charged; he observed that the effect was stronger when the conductor consisted of two metals than when of one.

Galvani's theory was opposed by Alexander Volta, of Pavia, who asserted that the phenomenon was due to electricity in the nerves, but that the electricity was disengaged by the contact of the two metals, the muscles and nerves only acting as conductors, the former manifesting the charge as an electroscope. He also proved by experiment, with what was called the *voltaic pile*, that electricity is disengaged by the contact of metals. This led to a noted controversy, which lasted for some time.

360. The **voltaic pile** consisted of a series of discs of copper, zinc, and wet cloth, arranged in successive layers in that order, so that, however many there might be, the lowest plate was copper and the highest zinc. (See Fig. 262.)

Thus each pair of metals in contact was separated from the next above it, by a piece of wet cloth, which also acted as a conductor; and all tended to produce a current of electricity in the same direction, the power of which became very great.* He also arranged a battery consisting of a connected series of cups, each containing the *voltaic couple*.

361. The **voltaic couple** consists of two metals connected by metal wires, and partly immersed in a conducting liquid. This forms a *simple galvanic circuit*.

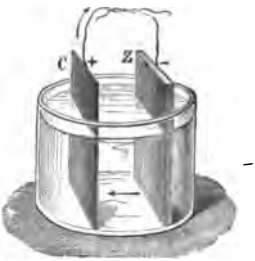


Fig. 261.

When a plate of zinc, Z (Fig. 261), and a plate of copper, C, are put into diluted sulphuric acid (oil of vitriol), no chemical action takes place, except that a few bubbles of hydrogen form on the surface of the zinc; but when the plates are brought into connection by means of the wires, hydrogen is given off in a much increased quantity, not from the zinc, but from the copper plate. The copper is, however, unchanged; but the zinc wastes away. When the wires are

* Thus was developed an apparently new species of electricity, exhibiting phenomena of a novel and very striking character; and capable of continuous production, without special precautions to prevent its escape, as with frictional electricity. The applications of this *dynamical electricity* were found to be so numerous and important, that it soon became, as it still is, the principal subject of electrical investigation, the other kind of electricity being of merely secondary value.

separated, the action ceases; and when they are brought together in the dark, an electric spark is observed, showing the passage of electricity from one to the other. This is spoken of as a *current;* but it is not to be conceived that there is any actual flow of matter, but only a movement as of sound or light.

The chemical action at the surface of the zinc causes a supply of positive electricity to the acid, and negative to the zinc; and these flow around to join each other through the circuit formed by the acid, the conducting copper and wire, and the zinc. The positive thus flows from the copper toward the zinc; and this is considered the *direction of the current.* When the metals are not in contact, the couple is said to be *open;* when they are connected, *closed.*

362. For the production of a voltaic current, it is only necessary that the chemical action upon one of the metals should be greater than upon the other. The metal which is most acted upon is called the *positive* or *generating plate,* and the other the *negative* or *collecting plate.* The force by which electricity is produced in the voltaic circuit is called *electro-motive force.*

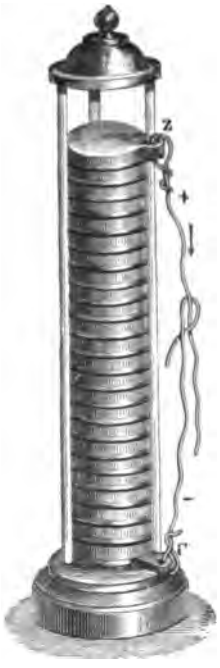


Fig. 262.

The current flows in the liquid from the positive, Z, to the negative plate C; and out of it, through the connecting wire, from negative, C, to positive, Z (Fig. 260); but, as already stated, it is the passage of the *positive electricity* that constitutes the current.

The direction of the current depends on the metals that are associated. In the following list, called an *electro-motive series,* when any two are placed together in dilute acid, the current passes from the lower to the higher: 1. Zinc; 2. Cadmium; 3. Tin; 4. Lead; 5. Iron; 6. Nickel; 7. Bismuth; 8. Antimony; 9. Copper; 10. Silver; 11. Gold; 12. Platinum; 13. Graphite. Thus iron is electro-positive toward copper, but electro-negative toward zinc; and copper is negative toward iron and zinc, but positive toward gold, silver, and platinum.

The direction of the current also depends on the nature of the liquid. Thus, in dilute sulphuric acid, lead is positive toward antimony; but in a solution of caustic potash, the reverse is the case.

A metal which is acted upon by a liquid is protected from chemical action by placing in contact with it one that is electro-positive toward it, thus causing a simple voltaic circuit. Sir Humphry Davy proposed to protect the copper sheathing of vessels from the action of the sea water by connecting zinc or iron with the copper. He found that a piece of zinc no larger than a nail would be sufficient to protect a surface of 40 or 50 square inches.

363. A **voltaic battery** consists of a connected series of voltaic elements, or couples, so arranged as to act together, like the Leyden jars of an electric battery (Art. 355).

The earliest of these was the *voltaic pile* (Art. 360). This is represented in Fig. 262. The discs of copper and zinc are separated by pieces of cloth wet with acidulated water, and kept in position by glass rods. It thus consists of a number of voltaic couples. This form of battery was soon found to be too inconvenient for use, and is now abandoned. The earliest modification was the *crown of cups*, also invented by Volta. Of this *Wollaston's battery* (Fig. 263) is an improved form. The plates Z are thick rolled zinc, the plates C are thin sheet copper, bent so as to encompass the zinc plates without contact, which is pre-

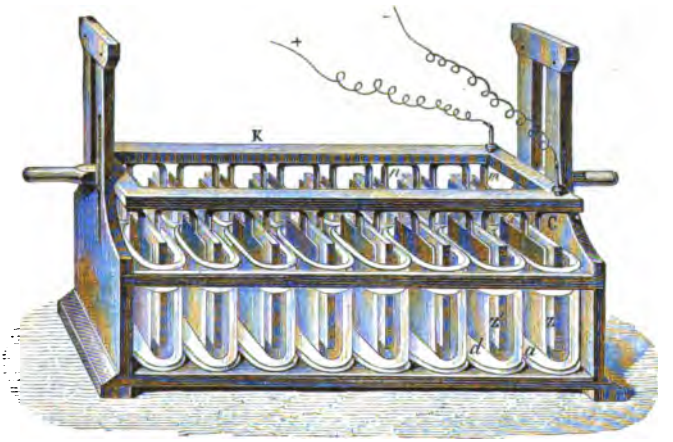


Fig. 263.

vented by small pieces of cork. The zinc and copper are connected into a couple by a copper strip, *o*; and the couples are connected. The sixteen couples are united in two series, and are all fixed to a frame of wood by which they can be raised or lowered, the couples being lifted from the liquid when not in use. Each separate couple with its containing vessel is sometimes called a *cell*.

364. The **poles** of a voltaic battery are the points at which positive and negative electricities respectively tend to accumulate. They are often called *electrodes*.

The term *electrode* is derived from the Greek words *electron* and *odos*, a way; since the poles, or electrodes, are the ways through which the electricities pass. The positive electrode is at the negative plate, and the negative electrode at the positive plate.

365. A **constant battery** is one in which the voltaic current

continues without change for a considerable period of time. In such batteries two liquids are used.

When a single liquid is used, the current becomes feeble, because the negative plate becomes polarized by the deposition of hydrogen on its surface. This is prevented by using a second liquid which acts chemically on the deposited hydrogen.

Daniell's battery, invented in 1836, was the first of this kind. A single cell, or element, of it is represented in Fig. 264. A glass or porcelain vessel, V, contains a solution of the sulphate of copper (blue vitriol), and in this is placed a perforated copper cylinder, G, open at both ends, at the upper part of which there is a rim or shelf, also perforated, in which is placed a supply of the copper sulphate, so as to keep the liquid constantly saturated. Inside the cylinder is a porous vessel, P, of unglazed earthenware, which contains dilute sulphuric acid or a solution of sulphate of zinc; and in this is placed a cylinder of zinc, Z. The elements are connected in the battery by two strips of copper, *p* and *n*.



Fig. 264.

The action is as follows: The hydrogen set free by the action of the dilute acid on the zinc, collects on the surface of the copper; but meeting the copper sulphate, it reduces it, forming sulphuric acid and copper, the latter of which is deposited on the copper plate, while the former passes through the porous cylinder, and thus serves to keep up a supply of sulphuric acid to act on the zinc. Were there not a constant supply of the sulphate, the hydrogen would accumulate on the copper plate, and stop the current. This form of battery produces a constant current for several hours.

In the *Hill battery*, a modification of the Daniell battery, the porous cup is dispensed with, the copper being placed in the bottom of the jar, and the zinc suspended from the top. A solution of the sulphate of copper is at the bottom, and a sulphate of zinc solution at the top of the vessel, being kept in position by their different specific gravities. Hence such a battery is called a *gravity battery*. The Calland element is similar in construction to the Hill battery.

In the *Grove battery* the porous cup contains strong nitric acid (aqua fortis) instead of sulphate of copper, and platinum takes the place of copper. The hydrogen unites with the oxygen in the nitric acid, forming water (oxygen and hydrogen) and nitrous oxide, which is dissolved, or passes off in nitrous fumes. It is a powerful battery, but made expensive by the platinum.

Bunsen's carbon battery, invented in 1843, is a Grove battery, in which a cylinder of carbon is used instead of platinum. The four parts of the battery, separate and in combination, are shown in Fig. 265. F is the vessel, of glass or stoneware, containing dilute sulphuric acid; Z, a hollow cylinder of zinc; V, a porous vessel, containing nitric acid; C, a stick of carbon—usually prepared by

mixing powdered coke and bituminous coal, and pressing the powder in a mold. To the carbon is fixed a binding screw, *m*, to which is attached a copper wire, forming the positive pole; and the zinc has a similar one forming the negative pole. The elements are connected into a battery, P.

In *Smee's battery*, which consists of a sheet of platinum between two plates of zinc, the collection of hydrogen on the negative platinum plate is prevented by roughening the surface of the platinum. Instead of platinum, silver covered with particles of platinum is frequently used. Only one liquid —dilute sulphuric acid—is required in this battery.



Fig. 265.

Many other forms of the voltaic couple have been devised, each having some specific advantages for particular purposes.

Batteries differ in the *quantity* as well as the *intensity* of the electricity developed by them. The former depends on the *size*, the latter on the *number*, of cells forming the battery. By connecting the copper plates and the zinc plates we get the effect of one large cell, producing a large quantity of electricity; but by connecting the zinc plate of one cell with the copper plate of the next, we produce intensity.

II.—EFFECTS AND USES OF THE VOLTAIC CURRENT.

366. **Physiological Effects.**—The influence of a voltaic current upon animal tissues is very remarkable. It gives activity to the nerves, causing the muscles with which they are connected to contract; or, when it acts upon the nerves of feeling, causing pain; or various sensations, as of light, taste, etc., when acting on the nerves of special sense.

367. **Heating Effects.**—The voltaic current acts like the discharge of an electric battery in passing through a metal wire, heating

it, sometimes to incandescence. With a powerful voltaic battery, all metals may be melted, even the most infusible, such as platinum.

Carbon is the only element which has not been melted by the voltaic current. A battery of 30 to 40 Bunsen's elements is sufficient to melt and volatilize fine wires of lead, tin, zinc, copper, gold, silver, iron, and even platinum. Iron and platinum burn with a brilliant white light; lead burns with a purple light; tin and gold, with a bluish white; copper and silver, with a green light. These effects depend on the intensity of the current, and therefore are determined by the size of the cells, not the number.

368. **Luminous Effects.**—When the electrodes of a powerful voltaic battery are brought very near together, a succession of brilliant sparks passes across the interval, producing a continuous light. This is the *electric light.*

When two pencils of charcoal are connected with the electrodes, as shown in Fig. 266, a beautiful effect is produced, the light assuming the form of a luminous curve, which is called the *voltaic arc.* It varies with the force of the current, and with a battery of sufficient power may exceed two inches in length. In a vacuum it is longer than in air. Its color and form vary with the conductors. Charcoal is one of the bodies which give the largest luminous arc.

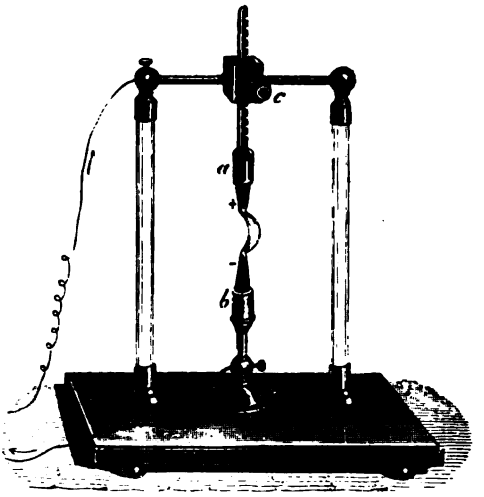


Fig. 266.

Sir Humphry Davy's experiments with the electric light, in 1801, were made with a battery of 2,000 plates, each four inches square. The carbon points used were of light wood charcoal, heated to redness and immersed in mercury, which penetrating the pores of the charcoal increased its conducting power. All substances became incandescent when placed in the voltaic arc of this battery. Platinum melted like wax in the flame of a candle; and even the hardest substances, such as sapphire and the diamond, were fused.

To prevent the decomposition of the charcoal by the oxygen of the air, these processes were effected in a vacuum; but the necessity of this is avoided by using gas graphite—a kind of carbon deposited in gas retorts, which is hard and compact, and burns very slowly in air.

Foucault's experiment consists in projecting on a screen, by means of a photo-

electric microscope,* the image of the charcoal points, when the electric light is formed (Fig. 267). The microscope is fixed to a brass box, within which are two charcoal points, separated by a short space exactly on the axis of the lenses. The electricity from a powerful battery reaches the points by means of copper wires; and the luminous arc produced is projected on the screen. The charcoal points can be easily seen; and the positive one is observed to become hollow and reduced in length, while the other increases, showing that matter is carried from the positive to the negative electrode.

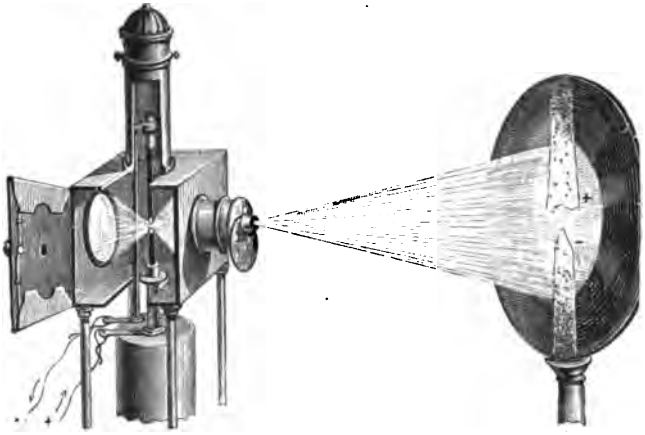


Fig. 267.

To render the electric light steady, a regulating apparatus is required to keep the distance between the carbon points uniform, by gradually bringing them together as they wear away. This is effected by means of contrivances of various kinds; and electric lamps are now constructed which can be employed for ordinary illuminating purposes. The advantages of the electric light over gas are the purity of its color, its great power and intensity, the absence of carbonic acid, since there is no consumption of the oxygen of the air, and its freedom from unpleasant odors. Besides it is cheaper, when the quantity of light is considered.

369. The **chemical effects** of the voltaic current are of a very interesting and important character, particularly in the decomposition of chemical compounds.

The first decomposition effected by means of the battery was that of water, in 1800, by Carlisle and Nicholson, using a voltaic pile. By the apparatus called

* The photo-electric microscope is the same as a solar microscope (Art. 298), except that the electric light is used instead of the solar light, to which it is preferable on account of its intensity, steadiness, and the readiness with which it can be produced at any time.

a *voltameter*, represented in Fig. 268, this can be conveniently accomplished. In the glass vessel containing water, mixed with some sulphuric acid to make it a better conductor, two platinum electrodes, *h* and *n*, are fixed. Two glass tubes filled with water are inverted over the electrodes, and when the current passes, bubbles of gas rise from the surface of each pole, and enter the inverted tubes. One of these is found to be oxygen, the other hydrogen, the former being about double the latter. Water may be analyzed by this process.

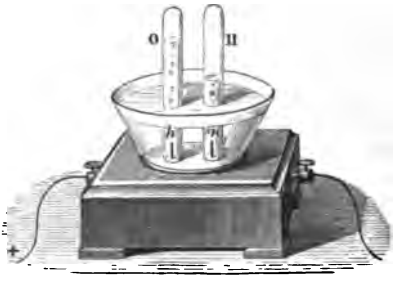


Fig. 268.

370. **Electrolysis** is the decomposition of a chemical compound by means of the voltaic current. The body resolved into its elements in this way is called an *electrolyte*, and is sometimes said to be *electrolyzed*.

These terms are those used by the great English chemist Faraday. Several substances supposed to be elementary have been shown to be compounds by means of the voltaic current. Davy decomposed the alkalies potass and soda, and discovered them to be oxides of the metals potassium and sodium, by means of a battery of 250 couples.

Electrolysis cannot take place unless the electrolyte be a good conductor. On this account, ice cannot be decomposed by the battery, since it is a bad conductor. Metallic bodies are only decomposed when in a melted state.

371. **Electrotypy** is a process by which, through electrolysis, metallic substances can be deposited on the surface of molds, type, engraved plates, seals, wood-cuts, metals, etc., so as to obtain an exact copy of the object in metal.

The art of *electro-metallurgy*, as it is called, was discovered independently by Thomas Spencer, in England, and by Professor Jacobi, in St. Petersburg, the invention being announced in 1839; although the germ of it may be traced to the experiments of Wollaston, Davy, and others of an earlier date. It may properly be regarded as a direct offshoot of the invention of Daniell's cell, in 1836.

The process consists in making a mold, in gutta-percha or wax, of the object to be copied, then covering its surface with some conducting material, as powdered graphite (plumbago, or black lead), and connecting it with the negative electrodes of a constant battery—Daniell's or Smee's, for example.

The most convenient arrangement for producing an electro-deposit of copper consists of a trough of glass, slate, or wood, lined with India rubber or coated with marine glue (Fig. 269). This contains an acid solution of the sulphate of copper, and across it are stretched copper rods, B and D, connected with the negative and positive poles of the battery. The molds *m* are suspended in the liquid from

the negative rod B; and a sheet of copper, C, is suspended from the positive rod D, at the distance of about two inches, opposite them. The copper plate keeps the solution at the same metallic strength; since the acid set free at the positive pole dissolves the copper, which supplies the place of that liberated at the negative pole, and deposited on the surface of the mold. After a sufficient quantity is deposited, it can be easily detached from the surface, and is then found to contain a perfect impression of the surface to be copied.

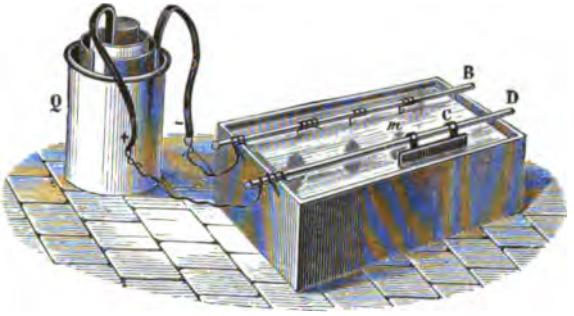


Fig. 269.

372. **Electro-plating,** a branch of electro-metallurgy, is the process of coating substances with gold or silver, by means of the voltaic current.

In *electro-gilding*, the substances to be plated are thoroughly cleaned, and then immersed in a bath containing a solution of gold, having been previously connected with the negative pole of a battery, to the positive pole of which a piece of gold is attached. This process can be used in plating silver, bronze, German-silver, brass, and copper; but iron, steel, zinc, tin, and lead are difficult to gild well. Usually they are first coated with copper, by means of the battery and a bath of copper sulphate, and are then gilded.

In *electro-silvering*, the process is the same except that the bath contains silver instead of gold, and a piece of silver is connected with the positive electrode.

The *steeling* of engraved copper plates is one of the most valuable applications of the electric deposit of metals by the bath. For this purpose the bath contains a solution of sal-ammoniac; a sheet of iron is suspended in it, connected with the positive pole, and a thin strip of iron connected with the negative pole. Iron from the large plate is dissolved in the sal-ammoniac; and when the solution contains enough iron, the copper plate is substituted for the thin strip. A very thin deposit of iron forms on the plate in a short time, giving it the appearance of a polished steel plate, the only difference in the surface being the hardness given to it; so that a great number of perfect impressions can be taken from it. When the coating of iron partly wears off, it can all be removed by dilute nitric acid, and the plate covered with another deposit.

III.—ELECTRO-MAGNETISM.

373. Electro-magnetism treats of the magnetic effects of the voltaic current.

The discovery by Oersted, in 1819, of the directive action excited by the voltaic current on a magnetic needle, became, by the researches of Ampère and Faraday, the source of a new branch of physics. This action may be shown by the following experiment: Let a copper wire, S N (Fig. 270), be suspended horizontally over a movable magnetic needle, *a b*, and parallel with it. When the current passes through the wire, as indicated, the direction of the needle will be changed; and the stronger the current, the greater will be the deflection.

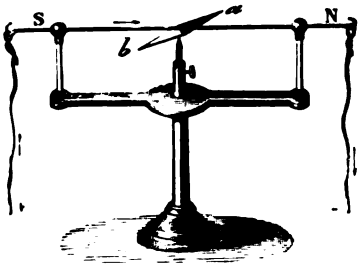


Fig. 270.

When the current passes above the needle and from south to north, the north pole of the needle turns to the west; but when it passes below the needle and from south to north, the deflection is toward the east. A change in the direction of the current, or in the position of the needle, reverses the deflection.

374. The galvanometer is an instrument for ascertaining the presence of a voltaic current, and measuring its force and direction.

The apparatus is represented in Fig. 271. It consists of a thick brass plate, D, resting on leveling screws; and on this is a rotating plate, P, of the same metal, to which is fixed a copper frame; and on the latter is a coil of insulated wire. Above the frame is a graduated circle, C, with a central slit parallel to the coil. By means of a fine silk thread an astatic system (Art. 329) is suspended, one of the needles, *a b*, being above the scale, the other,

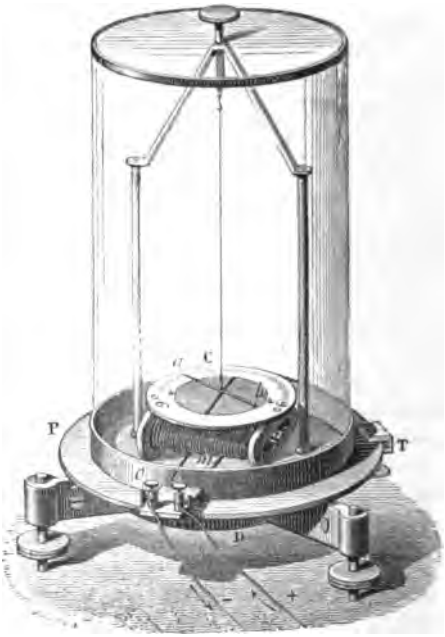


Fig. 271.

a', within the circuit. The plate P being turned so as to bring the zero-point in the scale, which is at the slit, in the magnetic meridian, the deflection of the needle shows the existence of the current, and its intensity and direction, according to the law explained in Art. 373. There are several different forms of the galvanometer.

Ohm's Law.—The laws governing voltaic currents were carefully investigated by Ohm, a German physicist. He discovered the celebrated law which bears his name: "The strength of a voltaic current is equal to the electro-motive force divided by the resistance."

The resistance to the passage of a current depends on the length and thickness of the conductor, as well as the conducting quality of the material of which it is composed; and the strength of the current is inversely proportional to the resistance.

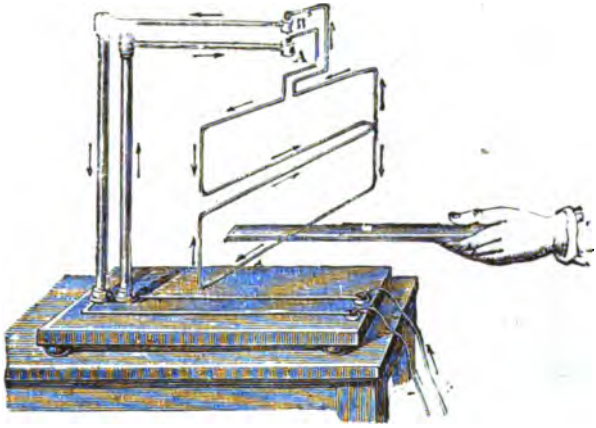


Fig. 272.

375. **Electro-dynamics.**—That department of the subject which treats of the action of electric currents upon magnets and upon each other, is called *electro-dynamics;* while that branch of physics which explains the laws of electricity in a state of rest is called *electro-statics.*

376. The fundamental law of electro-dynamics is: Two parallel currents in the same direction attract each other; but in contrary directions they repel each other.

377. Magnets act upon currents when the former are fixed and the latter movable, or the reverse.

In the experiment illustrated by Fig. 269, the magnetic needle, which is movable, is deflected by the fixed current; but in Fig. 272 this is reversed. The

circuit which the current traverses is movable at A and B; and when the powerful bar magnet is placed in its lower branch, the circuit begins to turn, stopping after some oscillations in a plane perpendicular to the axis of the magnet.

378. **Electro-magnets.**—A bar of iron placed within a coil of insulated wire through which an electric current is passing, is rendered



Fig. 273.

strongly magnetic, but loses its magnetism the instant the current ceases. Magnets formed in this manner are called *electro-magnets.*

Frictional electricity can be used for magnetizing (Art. 356), but the steady voltaic current is most effective for this purpose. If a spiral or helix be formed by coiling an insulated copper wire, as shown in Fig. 273; and if an unmagnetized bar, *a b*, be placed within it, the polarity of the bar while the current is passing may easily be shown. In a right-handed helix (Fig. 273), that is, one in which the direction of the coils is from left to right—like a common screw—the north pole is at the end at which the current passes out; in a left-handed helix, the reverse is the case. If a person imagine himself swimming in the direction of the current, and looking at the axis of the spiral, the north pole will always be on the left; and whether the helix be right-handed or left-handed, if the end facing the observer has the current flowing in the direction of the hands of a watch, it is a *south pole.* By reversing the direction of the current we change the poles of the magnet.

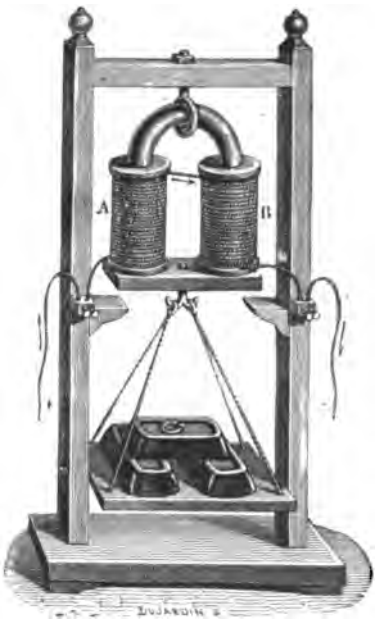


Fig. 274.

Electro-magnets have the horse-shoe form (Fig. 274), a copper wire covered with silk or cotton, being wound several times around them on the two branches A and B. In order that the two ends may be opposite poles, the wire must be wound in such a way that, if the horse-shoe were straightened out, the coil would be in the same direction throughout.

When the current passes through the helix, the armature is instantly drawn

to the magnet; and the connection as instantly ceases, when the current is broken. This is one of the most useful properties possessed by the electro-magnet.

The iron used for the electro-magnet must be pure, and made as soft as possible by being heated and cooled several times. A bundle of soft iron wires loses its magnetism more rapidly than a massive bar of the same size.

When a rod of soft iron is magnetized by a strong electric current, it emits a very distinct sound, at the moment of closing or opening the current. This is attributed to a vibratory motion of the molecules of iron, caused by their becoming successively magnetized or demagnetized.

The magnetization of an iron bar does not change its volume, but it diminishes slightly its thickness, and proportionally increases its length.

379. **Electric Telegraph.**—The electric telegraph is an apparatus by the use of which signals may be transmitted to a place at a great distance by means of a voltaic current. The two stations are connected by a single wire, the earth acting as the return conductor.

Besides being less expensive, the single wire is more effective; because the additional resistance of a return wire would be considerable, while the action of the earth causes none. It dissipates the electricity, instead of returning the same current to the battery.

It was proposed as early as the end of the last century to transmit signals to distant places by means of electricity. In 1811, a telegraph was invented in which the decomposition of water was employed to produce the signals. In 1834, an electro-magnetic telegraph was constructed, in which the current produced oscillations in a magnetized bar, which were observed with a telescope; and in this way intelligence was transmitted through a distance of more than a mile. In 1837, Steinheil in Munich and Wheatstone in London constructed telegraphs in which several wires were used, each acting on a single needle.* In the latter year, Steinheil discovered that the earth supplied the place of the return wire. Morse's telegraph, the simplest and the most general in use, was first exhibited in public in the city of New York, in 1837, and was first used May 27, 1844, between Washington and Baltimore. It is a *writing telegraph*, making its own record of the signals.

380. **Morse's telegraph** is constructed on the principle that an electro-magnet can be instantly made and unmade by closing or breaking the voltaic circuit. It consists of three parts: the *indicator*, the *communicator*, and the *relay*, besides the metallic wire connection between the stations.

The *indicator* or *register* is represented in Fig. 275. The current enters by the wire C, and passes into an electro-magnet, E, which, the instant the circuit is closed, attracts the armature A, and this acts upon a lever which moves on the

* The first telegraphs constructed for commercial use were laid down by Wheatstone and Cooke, on the London and Birmingham and the Great Western railways. Their expensiveness soon led to their abandonment.

axis x, the lever being raised by a spring, r, as soon as the circuit is broken. At the other end of the lever, a pencil records the signals upon a strip of paper, $p\ p$, rolled round the drum R, from which it is rolled on the second drum Q. The paper being set in motion, the point indents it, the shape of the mark de-

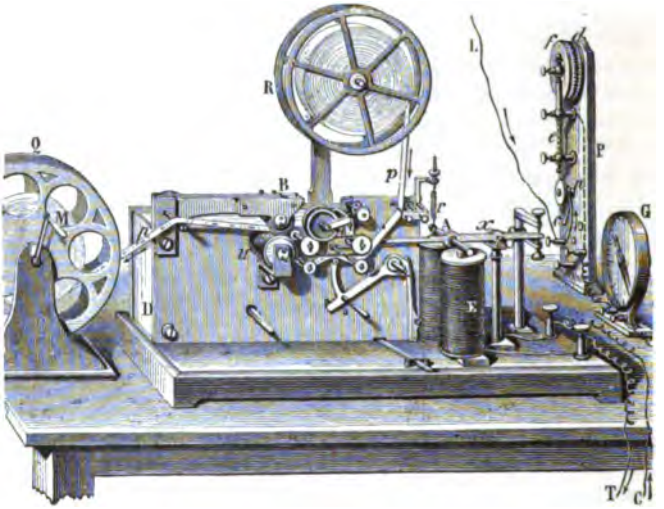


Fig. 275.

pending on the time during which the point rests on the paper—being sometimes only a dot or a short stroke, and sometimes a dash. The combinations of short and long strokes constitute the Morse or dot and dash alphabet, which is now universally employed for telegraphic writing. It is given below.

MORSE'S ALPHABET.

A · —	J — · — ·	S · · ·	1 · — — —
B — · · ·	K — · —	T —	2 · · — — ·
C — · — ·	L — —	U · · —	3 · · · — ·
D — · ·	M — —	V · · · —	4 · · · · —
E ·	N — ·	W · — —	5 — — — —
F · · — ·	O — —	X — · · —	6 — · · · · ·
G — — ·	P · — — ·	Y — · — —	7 — — — · ·
H · · · ·	Q — — · —	Z — — · ·	8 — — · · ·
I · ·	R · — ·	& · — · · ·	9 — — · —

The naught (0) is a long dash (——). A space is left between the letters, and a longer one between the words. There are signs also for the punctuation marks. Telegraph operators soon become so familiar with the sounds, that they are able to read the message without any recording apparatus, using only what is

called a *sounder*, which is an instrument consisting of a small electro-magnet and an armature, that produces a sharp click when the armature strikes against the magnet.

The *communicator*, or *key*, consists of a small mahogany base, which acts as a support for a metallic lever, *a b* (Fig. 276), moving on an axis. The extremity

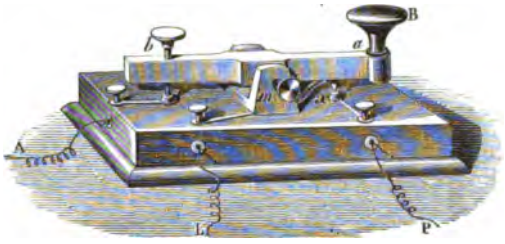


Fig. 276.

a of the lever is kept up by a spring, and is forced down by pressing on the key B, striking on the button *x*. There are three binding screws connected with the wires—P coming from the positive pole of the battery, L the line wire, and A connected with the indicator.

When a message is to be received, the current arriving by L passes to the metallic piece *m*, and thence to the indicator by A. When a message is to be transmitted, the key B is pressed, so as to bring the lever down on *x*, and close the circuit. The current coming from P, passes through *m*, and thence along L to the distant station. According to the time the key B is pressed, a short or long stroke is produced in the indicator.

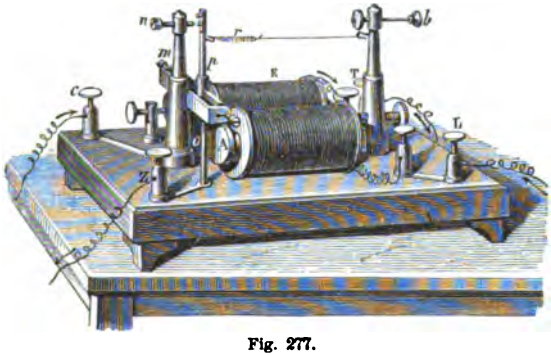


Fig. 277.

The *relay* is an auxiliary electro-magnet, used in connection with a local battery to furnish the power needed to write the signals, when, owing to the distance traveled, the primary current is too much weakened to do this. A relay instrument is represented in Fig. 277. The current enters at L, passes into the

electro-magnet E, and thence into the earth at T. This current causes the armature A to be attracted, which acts on the lever p and this pressing upon the button n, allows the current from a local battery which enters at c, and ascends the column m, to pass into the lever p, whence it descends by the rod o, by which it is transmitted to the screw Z; thence it enters the electro-magnet of the indicator, and emerges by the wire Z, returning to the local battery. The spring r serves to draw the lever p from the button, when the electro-magnet ceases to act. As the oscillations of the lever are caused by the manipulations of the local battery, all the signals are exactly transmitted by the relay.

When the current of the main circuit is strong enough to dispense with the local circuit and sounder, the relay is used as a sounder, more play being given to its lever so as to increase the click. Quite often a *main line sounder* is employed, and various devices are resorted to in order to increase the sound, when the main line current is too feeble.

A general battery of 25 Daniell's elements produces a current strong enough to work a relay at a distance of at least 90 miles; but for a longer distance a new current must be taken. This is effected by still another battery, called a *postal battery*, or *repeater*. The current from this enters by a special wire, and, when the armature A (Fig. 275) sinks, is carried by a contact through another wire, to the wire of the line, which carries it to the next post.

The galvanometer, G, is used to show that the current is passing; from this the current goes to the communicator, at L (Fig. 276), whence it passes to A, and goes to the relay (Fig. 277), which it enters at L, working the electro-magnet, and thus forming the connection with the local battery to mark the signals.

While the telegraph office is closed, or during a severe electric storm, it is necessary to disconnect the instruments from the line. This is accomplished by what is called a *cut-out*, which is a contrivance to complete the circuit, leaving the instrument outside of it, or *cut out*.

The *lightning arrester* is intended to prevent the injurious effects of atmospheric electricity, a great discharge of which would be apt to burn the fine wire coils of the relay magnet. By means of the arrester, the atmospheric electricity entering the office by the line wires is conducted to the ground wire, and thence to the ground. It is of various forms; but the principle of its construction is, that atmospheric electricity, being of a great intensity, will leap over a slight break in the conductor, and pass to the ground, while the feebler galvanic current is confined to the wire.

Cowper's writing telegraph reproduces at a distance a fac-simile of a person's handwriting.

381. The **electric alarm** is an apparatus for calling attention at a distance by means of an electric current.

Fig. 278 represents one form of such an instrument. E is an electro-magnet fixed vertically to a board. The line wire connects with one end of the wire of the magnet at m; the other end of the magnetic wire is connected with a spring, c, to which is attached the armature a. This is pressed by a spring, C, which connects with a wire that is joined at n to the wire leading to the earth. When

the circuit is closed, the armature moves the hammer P, which strikes against the bell T. This breaks the circuit, and the magnet ceases to act; but the spring *c* now brings the armature in contact with the other spring, C, and the circuit is again closed, thus causing the bell to ring again. In this way a continuous alarm is kept up as long as the current flows in at *m*.

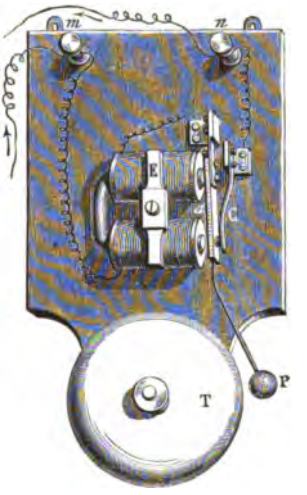


Fig. 278.

382. **Electro-motors,** or **electro-magnetic engines,** are machines in which the motive power is supplied by electro-magnets, causing alternate movements in their armatures, as in the Morse telegraph; or on the principle that a change in the direction of the current reverses the poles of the magnet.

The first engine of this kind was invented by Prof. Henry, of Washington, in 1831. A large electro-magnetic engine was constructed at St. Petersburg, in 1834; and one constructed by Prof. Page, of Washington, at the Government's expense, had sufficient power to propel a railroad car with considerable speed. There have been many attempts to make such engines available for the general purposes of machinery, but with only partial success on account of the expensiveness of the battery required to produce the current. The cost of the acids and the zinc which they use is much greater than that of the fuel required for steam-engines of the same capacity.

IV.—VOLTAIC INDUCTION. MAGNETO-ELECTRICITY.

383. **Induced currents** are those which are produced in metallic conductors through the influence of currents passing through other conductors, or by the influence of powerful magnets; and sometimes by the magnetic action of the earth.

This is analogous to electrical induction (Art. 340); and can be shown by winding a quantity of insulated (silk-covered) copper wire upon a cylinder of wood, B (Fig. 279), and upon this winding a greater length of fine copper wire also insulated in the same way. The outer wire, called the *secondary coil*, is connected, by the binding screws *a* and *b*, with wires which pass to a galvanometer, G; and the inner wire, or *primary coil*, is connected with *c* and *d*, forming a voltaic circuit with a battery. Thus the voltaic current passes through the primary coil alone, and its induced effect on the secondary coil is shown by the galvanometer, which is connected only with that coil.

The movement of the needle shows that, at the instant the circuit is closed,

that is, immediately the current begins to pass through the thick wire, there is induced in the secondary coil a current in the opposite direction. The effect is only instantaneous, the needle immediately returning to zero, and continuing at rest as long as the current is passing; but the instant the circuit is broken, an induced current is shown in the secondary wire, but then in the *same direction* as the inducing current.

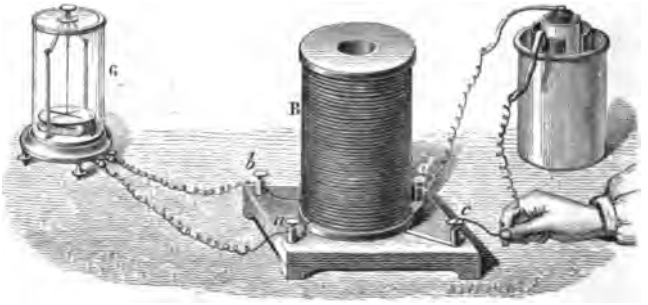


Fig. 279.

384. The **law of voltaic induction** may be thus briefly stated: A current, at the moment the circuit is closed, produces in an adjacent conductor an inverse current; and, at the moment it is broken, a direct current; but while the distance between the conductors remain unchanged, a constant current does not produce this effect.

To this it may be added, a current which is removed, or whose intensity is diminished, induces a *direct current;* but a current which is approached, or whose intensity is increased, induces an *inverse current.*

385. Induced currents are also produced in metallic conductors by the action of a magnet.

This was shown by Faraday by means of a coil of wire 200 or 300 yards in length. The experiment is as follows: The two ends of the wire being connected with a galvanometer, a strongly magnetized bar is suddenly inserted within the coil (Fig. 280). The induced current is thus rendered apparent. The induction can also be shown by placing a bar of soft iron within the coil, and suddenly bringing a powerful magnet in contact with it, the induction being then produced by the magnetization of the soft iron bar by means of the permanent magnet.

A similar effect is produced by rapidly rotating a magnet in front of an electro-magnet, in such a way as to cause the poles to act in succession on the branches of the electro-magnet, thus inducing a current in its wires. Also when a plate of soft iron is passed rapidly in front of the poles of an electro-magnet, the iron

becoming a magnet induces currents in the wire alternately in different directions.

Terrestrial magnetism acts, in its inducing influence, as if a powerful magnet were placed in the interior of the earth, in the direction of the dipping needle. This was discovered by Faraday, who demonstrated the fact by placing a long helix of insulated copper wire in the plane of the magnetic meridian parallel to

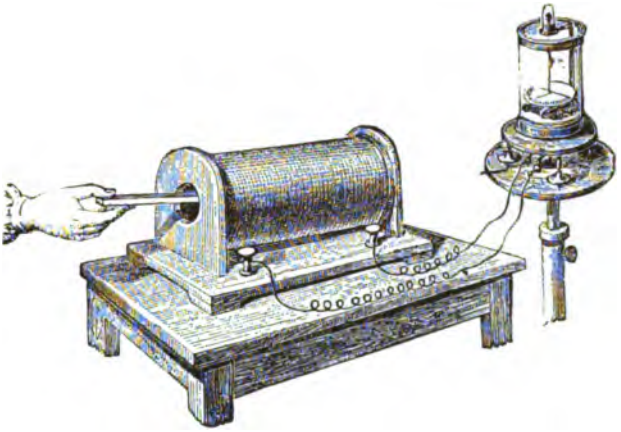


Fig. 280.

the dipping needle. Then, by turning the helix half round on an axis passing through its middle, and perpendicular to its length, it was seen that the needle of the galvanometer was deflected at every turn.

386. Induced currents have all the properties of ordinary currents, producing strong luminous, calorific, chemical, and physiological effects, and causing other induced currents.

They act on the magnetic needle, and magnetize steel bars when passing through a wire coiled around the bars; and they, moreover, produce a shock like that from accumulated electricity. In some of these effects, there is considerable difference between the direct and the inverse current. For example, the former magnetizes completely, while the latter does not magnetize at all.

387. **Magneto-electricity.**—Electricity induced by the action of magnets is called *magneto-electricity*. Its production is due to the principle of magneto-electrical induction discovered by Faraday, in 1831, by the operation of which electric currents are produced in conductors when they are moved in a magnetic field (Art. 320).

To generate an electric current the conductor must be moved rapidly across the lines of magnetic force. This causes an electro-motive current in the con-

ductor, in a direction at right angles to its motion, and having an intensity proportionate to the number of lines of force cut in a given unit of time. It depends, therefore, on the extent and intensity of the magnetic field, and the velocity with which the conductor is moved in it.

388. **A dynamo-electric machine, or dynamo, is a machine the object of which is to convert mechanical energy into that of electric currents, or electric energy into mechanical force, by rotating conductors in the form of coils of wire in a magnetic field.**

When a permanent magnet, or magnetic battery, is used to supply the magnetic field, the machine is sometimes called a magneto-electric machine; but in principle there is no difference between the two kinds of machines.

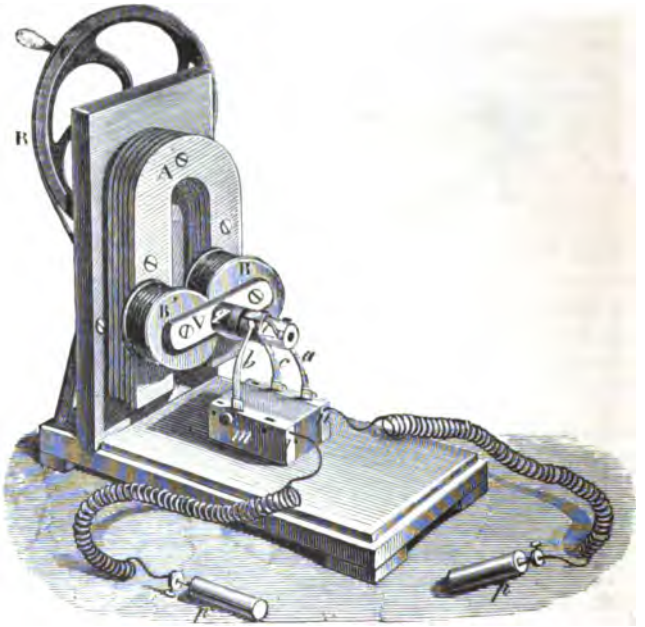


Fig. 281.

Clarke's magneto-electric machine was constructed to produce an uninterrupted series of electric sparks by means of magnetism. It is shown in Fig. 281. A powerful horse-shoe magnetic battery, A, is fixed against a wooden support, and in front of it are two coils, B and B', movable round a horizontal axis. The coils are formed of insulated wire wound around cylinders of soft iron, joined at one end by a plate of soft iron, V, and at the other by a similar plate of brass. These two plates are fixed on a copper axis, upon which they are rotated

by means of the wheel B. One end of the coil B is connected, on the axis of rotation, with one end of the coil B′; and the other ends of the coils terminate in a copper ferule *q*, fixed to the axis, but insulated. That the induced current may be in the same direction in each coil, the wire is coiled on the two bobbins in different directions. When the electro-magnet turns, its two branches become alternately magnetized in contrary directions under the influence of the magnet A, and a current is induced in each wire, the direction of which is changed at each half of a rotation (Art. 384). The induced currents of opposite electricities pass through the wires to the handles *p p*, and cause powerful convulsive shocks when they are grasped. By such a machine, when the armature formed by the coils is rapidly rotated, strong luminous, chemical, or heating effects may be produced.

In the dynamo-electric machine, or *dynamo*, as it is called, electro-magnets take the place of the permanent magnet. Such machines when of considerable size, and driven with great velocity by means of a steam-engine, have immense

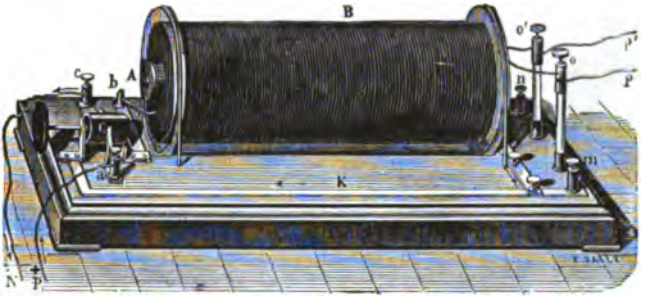


Fig. 282.

power. The electric light used for illumination is thus produced, and the dynamo is also employed in electro-metallurgy. Great improvements have recently been made in dynamo-electric machinery. Instead of converting mechanical force into electric energy, the action of the dynamo may be reversed, converting electric energy into mechanical force. In this way it has been used as a motor, for the purpose of propelling carriages along a railway.

389. An **induction coil** is a coil so arranged as to produce strong induced currents by the action of a voltaic current, the circuit of which is alternately opened and closed in rapid succession.

This apparatus has several constructions, but essentially it consists of a hollow cylinder, in which is a bar of soft iron, or bundle of iron wires, with a double coil of insulated wire around it, one coil being connected with the poles of a battery, the circuit of which is alternately opened and closed by a self-acting apparatus, the other producing the induced current.

Ruhmkorff's coil, represented in Fig. 282, is a contrivance of this kind. The primary or inducing coil is of copper wire, coiled on a cylinder of cardboard,

which is inclosed in an insulating cylinder of glass or India rubber. On this is wound the secondary coil of much finer copper wire. The insulation is increased by interposing melted shellac between the wires. The length of the secondary wire is very great, sometimes several miles—in Spottiswoode's machine it was 280 miles. The potential of the induced electricity depends to a great extent upon the thinness and length of this wire.

The current enters by the wire P, and passes from the binding screw *a* to the *commutator* or *key*, which serves to break the circuit or send the current in either direction; then, by the screw *b*, it enters the primary wire, and acts by induction on the secondary wire. Having passed through the primary coil, it passes to a movable piece of iron, *o*, called the *hammer*, descends to a copper plate, K, and is carried by that to C, whence it goes to the negative pole of the battery by the wire N. The current is only induced when the circuit is opened and closed, and this is effected by the alternate rising and falling of the hammer *o*.



Fig. 283.

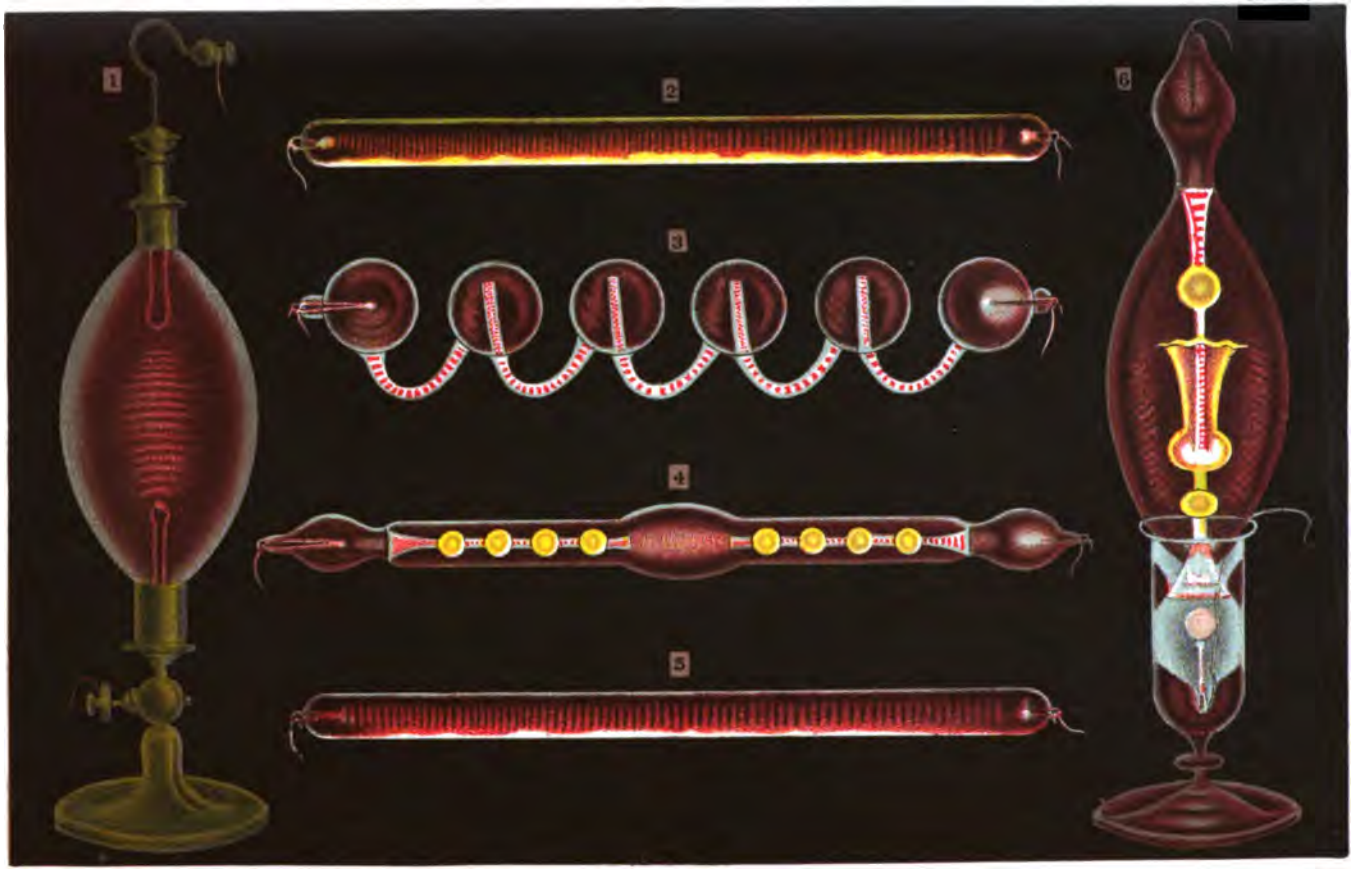
The induced current which can thus be developed, is of immense power. Gases may be decomposed or combined, and luminous effects of great variety and beauty produced, according as they take place in air, in a vacuum, or in vapor of different kinds. In a vacuum, if the vapor of turpentine, alcohol, or certain other substances, have been introduced before exhaustion, the light assumes the appearance of alternate bright and dark zones between the two poles (Fig. 283). The light of the positive pole is generally red, and that of the negative pole violet. The tints, however, vary with the vapor or gas that is present.

Geissler's Tubes.—These effects are most brilliant when the discharge from the coil takes place in glass tubes containing a highly rarefied vapor or gas. This phenomenon was first investigated in this way by Geissler of Bonn; and hence the tubes have been called *Geissler's tubes*. The tubes, having been filled with different gases or vapors, are exhausted, and the current is admitted by means of platinum wires soldered into the glass at the ends of the tube. The fluorescence which the electric discharge excites in the glass sometimes heightens the brilliancy and beauty of the effects presented. (See Plate III.)

Geissler's tubes have been used for medical purposes, being inserted into cavities of the body, and affording the light required for examination.

390. The **telephone** is an apparatus by means of which sounds can be transmitted to a great distance by an induced current.

A section of the instrument, showing its construction, is presented in Fig. 284. In a wooden case or holder is contained a steel magnet, M, about four inches in length and half an inch in diameter, around one end of which is fitted



ELECTRIC DISCHARGE IN RAREFIED GASES.

1 Discharge in Vapour of Alcohol. (2 3 4 5 Geissler's Tubes enclosing rarefied Gases.) 2 Shows the Fluorescence of Sulphuret of Calcium. 4 Fluorescence of Uranium glass.
6 Fluorescence of Uranium glass, and of Sulphate of Quinine.

a coil of fine insulated copper wire wound upon a thin flat bobbin, B. The ends of the coil pass through apertures L L in the case to the screws C C. In front of the magnet, at a distance which can be adjusted by a screw, is a disc, D, of soft iron, as thin as a sheet of stout letter-paper. This disc is screwed down by the mouth-piece E. One of the wires C leads to the station to be communicated with, the other is connected with the earth. The action is as follows: The magnet M, by induction, magnetizes the soft iron disc D; but by the vibrations of the air, caused by the voice, this disc is moved backward and forward; and thus the strength of the magnet M is either increased or diminished. By induction these effects are imparted to the coil B, giving rise to currents that are transmitted by C, and cause corresponding effects in the disc of a similar instrument at the other station, these effects being transmitted to the ear by the vibrations of the air.

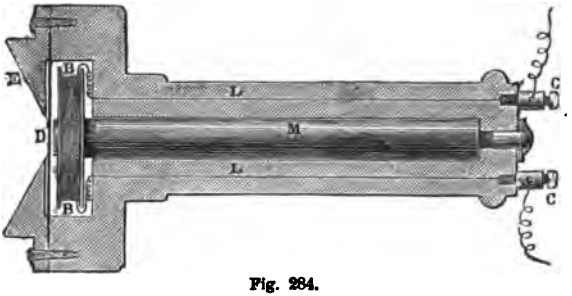


Fig. 284.

Each instrument can thus be used as a sender or receiver, but it has been found more convenient to use two instruments, one for the ear and the other for the voice, the latter being the larger and more powerful. The reproduction of the sounds is nearly perfect, but they are much weakened. It has been estimated that not more than one ten-thousandth part of the sound is transmitted, showing the wonderful perfection and delicacy of the human ear, that is capable of perceiving it. It has been also estimated that by the telephone no less than 24,000 currents are transmitted in a single second.

391. The **microphone** is an instrument used in connection with the telephone, to intensify low or weak sounds, by means of fluctuations in the current of electricity.

This remarkable instrument was invented by Mr. Hughes, and depends on the principle that when the wires of an electric circuit, in which is interposed a telephone, are broken, and rest loosely on each other, sounds made near the point of contact are greatly augmented in the telephone. A simple form of the apparatus is represented in Fig. 285. A is a piece of thin wood fitted vertically to a base, B, of the same material. C C are two small rods of gas carbon, a semiconductor, fixed in the board A; and a spindle of the same substance is pivoted between the rods, which are connected to the wires forming the circuit of a small

battery and a telephone. The carbon causes a slight break in the current and increases the resistance, while any compression of the carbon diminishes the resistance. Thus the slightest jar at the base B causes a variation in the pressure; and these variations in pressure produce fluctuations in the current which are transmitted to the receiver of the telephone. Every sound is therefore magnified. The ticking of a watch, the rustling of silk, or the scratch of a pin, becomes perceptible a hundred miles distant; while the fall of a drop of water on the base produces a loud crash.

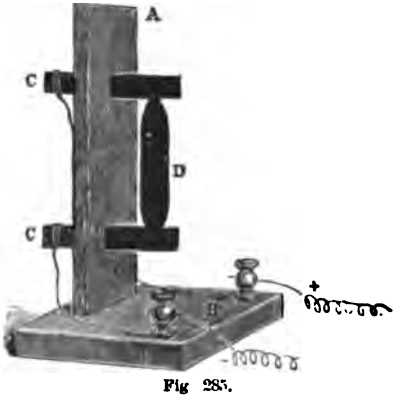


Fig 285.

392. The **tasimeter** is an instrument used to ascertain or measure very small changes in the length of bodies. It depends, like the microphone, on the principle that the resistance of carbon forming part of a voltaic circuit, varies greatly with the pressure to which the partially conducting substance is exposed.

The instrument is shown in Fig. 286. It consists of an iron base supporting two uprights, one of which, *a*, is connected with a galvanometer, *g*. An ebonite

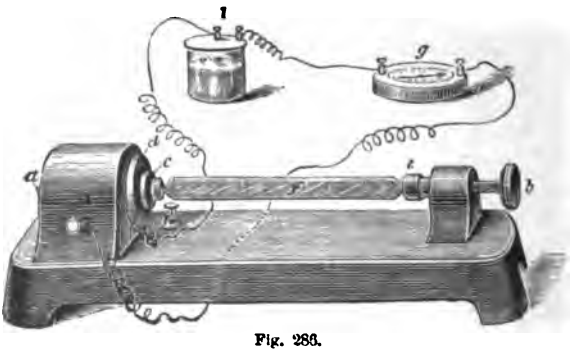


Fig. 286.

disc, *d*, is screwed into *a*; and in a cavity of the ebonite is a small disc of carbon, in the outer surface of which is a strip of platinum connected with one of the poles of the battery *l*. The metal plug *c* closes in the carbon disc, and by means of a small hollow in its outer face holds, with a similar plug, *e*, the body *f*, to be experimented on. The screw *b* acts on the plug *e*, and compresses lightly the substance *f*. The slightest pressure of the screw is indicated by the galvanometer;

and further expansion or contraction of the substance is shown by the subsequent deflection of the needle. Thus, if it be a thin strip of ebonite, the heat of the hand held near it causes an expansion which is shown by the galvanometer. It has been used to show the slight elongation of an iron rod when it is magnetized.

V.—THERMO-ELECTRICITY.

393. **Thermo-electricity** is electricity produced by the action of heat. Its properties are the same as ordinary electricity.

That electricity is generated by heat is illustrated by an experiment made in 1821 by Professor Seebeck, of Berlin. A copper plate with bent ends, *m n* (Fig. 287), is soldered to a plate of bismuth, *o p*, and a magnetic needle, *a*, is placed between, moving on a pivot. The apparatus being in the magnetic meridian, if

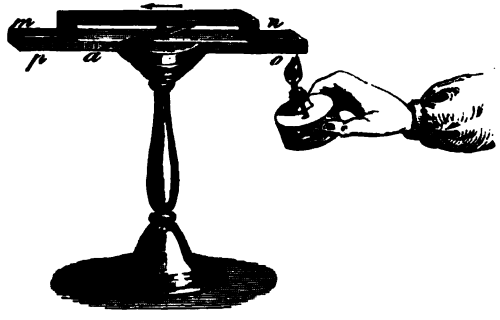


Fig. 287.

heat is applied to one end, *o*, the needle is deflected in such a manner as to indicate that an electric current passes from *n* to *m*, from the heated to the cool portion of the copper; and when ice is applied at *o*, a contrary current is developed. This is called the *thermo-electric current.*

394. A **thermo-electric couple** consists of two metals soldered together so that the two ends may be connected with a conductor. Several of these couples, or elements, when properly united, form a *thermo-electric battery.*

395. A **thermo-electric pile** is a battery consisting of a number of alternate bars of antimony and bismuth soldered together.

This form of battery has the advantage of combining a large number of elements in a small space. The pile is represented in Fig. 288; the manner in which the couples are joined is shown in Fig. 289. The series of five couples, insulated by varnished paper bands, are inclosed in a copper frame, P, and may be joined to other series formed in the same way. The binding screws, *m* and *n*,

which communicate, one with the first plate of antimony, the other with the last plate of bismuth, are, respectively, the positive and negative poles of the battery. This is called, after the name of its inventor, *Nobili's pile*. There are several other forms of the thermo-electric battery.



Fig. 288.



Fig. 289.

The thermo-electric battery is a very delicate test for changes of temperature; the electric currents are of low potential, but are very steady and uniform, since their opposite junctions, by means of melting ice and boiling water, can easily be kept at 0° and 100° C.

Other metals may be used in the thermo-electric battery in the place of antimony and bismuth. The best adapted are, besides those, German-silver, copper, iron, and brass. German-silver and brass in combination form very effective elements.

When the poles of a thermo-electric battery are connected with a galvanometer, the smallest variation in temperature is indicated. The heat of the hand held near it—even the warmth emitted by the body of a fly—causes a deflection of the needle. Thus these small portions of heat become visible by being changed first into electricity, next into magnetism, and then into motion.

VI.—ANIMAL ELECTRICITY.

396. **Animal electricity** is that which is found to exist, to a greater or less extent, in the bodies of animals. While some by their peculiar constitution, as electrical fish, possess the power to generate large quantities of electricity, sometimes at will, the muscles and nerves of all animals may be shown to be the source of electrical currents.

The existence of such currents was shown by Galvani; but, on the invention of the voltaic pile, his researches attracted but little attention. Since then, this branch of research has been diligently prosecuted.

Muscular currents may be investigated by experimenting with the living irritable muscles of a frog, applying the electrodes of a battery to different sections of the muscle, and noticing the effect of the current on the galvanometer. Various facts are determined in this way. By using another muscle as a galvanoscope, the galvanometer may be dispensed with in these experiments. Thus, if the nerve of one living muscle be dropped suddenly on another living muscle, so as to come in contact with its longitudinal and transverse sections, a contraction of the first muscle will occur, because its nerve is stimulated by an electric current derived from the surface of the other muscle. Nerves give the same indications of electro-motive force as muscles.

397. **Electrical fish** give, when touched, shocks like that of a

charged Leyden jar. Of these fish, the gymnotus, or electric eel, and the torpedo are examples.

The peculiar character of these creatures has been carefully investigated by scientists. The gymnotus was examined by Humboldt and Bonplane, in South America, and by Faraday in England; and the torpedo has been made the subject of close scientific scrutiny in France and Italy.

The shock which these animals give is purely voluntary, serving for offense and defense. The shock of the gymnotus was found by Faraday to be equal to that of a battery of 15 Leyden jars exposing a coating of 25 square feet. Horses have been killed by a shock of this fish. Repeated shocks exhaust the powers of the animal.

The fact that the shocks produced by these animals are caused by ordinary electricity has been conclusively shown by various experiments. For example, if the back of the fish is touched with one hand, while the under part is touched with the other, or with a metal rod, an electric shock is received, sometimes of considerable violence, while none is felt if the animal is touched by a non-conductor. The same fact is shown by letting the current pass through a galvanometer, the deflection of the needle indicating the passage of the current from the upper to the lower side of the animal. Moreover, if the current from a torpedo is passed through a helix inclosing a steel bar, the latter becomes magnetized. Prof. Carpenter says: "Although no one has ever seen a spark emitted from the body of one of these fish, it may easily be made manifest by causing the torpedo or gymnotus to send its discharge through a slightly interrupted circuit."

These animals are supplied with special organs for the production of electricity. In the torpedo "the electric organs occupy the front and sides of the body, forming two large masses which extend backward and outward from each side of the head." These organs are supplied with nerves of very great size. When these nerves are cut, the animal loses its electric power, but is in no other way injured.

SYNOPSIS FOR REVIEW.

GALVANIC OR DYNAMICAL ELECTRICITY.

I.—GALVANIC OR VOLTAIC BATTERIES.

1. *Galvanic or Voltaic Electricity.*
 Galvani's and Volta's discoveries and experiments.
2. *Voltaic Pile.*—Voltaic couple, or simple galvanic circuit.
 1. Direction of current.
 2. Electro-motive series.
3. *Voltaic Batteries:*
 1. Wollaston's.—Poles or electrodes.
 2. Constant battery.
 3. Daniell's " —Hill battery.
 4. Grove "
 5. Bunsen's "
 6. Smee's "

II.—EFFECTS AND USES OF THE VOLTAIC CURRENT.

1. *Physiological Effects.*
2. *Heating Effects.*
3. *Luminous Effects.*—Voltaic arc.
4. *Chemical Effects.*
 Electrolysis.
 Electro-metallurgy: { Electrotypy. / Electro-plating.

III.—ELECTRO-MAGNETISM.

1. *Galvanometer.*
 Construction and use.
2. *Electro-dynamics:*
 1. Fundamental law.
 2. Electro-magnets: Construction and use.
 3. Electric telegraph.
 1. Morse's telegraph: { 1. Principle. / 2. Parts. / 3. Uses.
 2. Cowper's writing telegraph.
 4. Electric alarm.
 5. Electro-motors.

IV.—VOLTAIC INDUCTION.

1. *Induced Currents:*
 1. Law of voltaic induction.
 2. Magneto-electrical induction.—Magneto-electricity.
 3. Dynamo-electric machines.
 4. Induction coil.—Ruhmkorff's coil.—Geissler's tubes.
 5. Telephone and microphone.
 6. Tasimeter.

V.—THERMO-ELECTRICITY.

1. *Thermo-electric Current.*
2. *Thermo-electric Pile and Battery.*

VI.—ANIMAL ELECTRICITY.

1. *Definition.*
2. *Muscular and Nerve Currents.*
3. *Electrical Fish.*

APPLICATION OF PRINCIPLES.

1. On what principle did Galvani explain the contraction of the frog's legs? 2. What was Volta's explanation of the phenomenon? 3. What chemical action takes place in the simple voltaic circuit, and how does that cause a current? 4. What would be the effect, if the chemical action were equal in the two metals? 5. What determines the direction of the current? 6. If iron and copper were coupled, how would the current flow? 7. How did Sir Humphry Davy propose to protect the copper sheathing of vessels from the action of the sea-water? 8. What is the advantage of using two liquids in a voltaic cell over a single liquid? 9. How does Daniell's battery differ from the Grove battery? 10. From Bunsen's battery?

11. What is the peculiar construction of a gravity battery? 12. Why is carbon used for the points of the electrodes? 13. How may the carbon points be seen while the current is in action? 14. Why is a regulating apparatus required to make the electric light steady? 15. What advantages has the electric light over that of gas? 16. How have new elements been discovered by means of the voltaic current? 17. Why cannot ice be decomposed by electrolysis? 18. What is the principle upon which the electrotype process is based? 19. Why are iron or steel articles coated with copper before being electro-gilded? 20. On what principle is the construction of the galvanometer based?

21. What principles are concerned in the construction and action of an electro-magnet? 22. How is the direction of a voltaic current through a helix determined? 23. How may the poles of an electro-magnet be distinguished? 24. Why, in forming a circuit for an electric telegraph, is no return wire needed? 25. For what is the ground wire used? 26. What principles are concerned in the construction of Morse's telegraph? 27. Why is a relay battery used? 28. How can the register be dispensed with? 29. What is the use and principle of action of a lightning arrester? 30. When and why should the cut-off be used?

31. What is the principle of the electric alarm? 32. How is the fact of voltaic induction proved? 33. Why is mechanical force required to produce magneto-electricity? 34. What is the effect of moving a conductor across the lines of force in a magnetic field? 35. How may the voltaic induction of the earth be shown? 36. On what principle are dynamo-electrical machines constructed? 37. When does a dynamo become an electro-motor? 38. What principles are applied in Clarke's magneto-electric machine? 39. For what purpose is steam applied to the dynamo? 40. What is the principle of Ruhmkorff's coil? 41. For what are Geissler's tubes used? 42. What principles are concerned in the construction of the telephone? 43. What in the microphone? 44. In the tasimeter? 45. In the thermo-electric battery?

CHAPTER XI.

METEOROLOGY.

398. **Meteorology** is that branch of physics which treats of the phenomena of the atmosphere.

To all such phenomena the term *meteors* is scientifically applied; although, in common use, the word *meteor* is restricted to a shooting-star or a fire-ball. Meteors may be classed as *aërial meteors*, such as winds, tornadoes, etc.; *aqueous meteors*, as fogs, clouds, rain, snow, hail, and dew; and *luminous meteors*, as the rainbow, lightning, halos, and the aurora borealis.

399. **Winds** are currents in the atmosphere, varying in their direction and velocity.

The direction of the wind is indicated by the point of the compass from which the current flows. Thus a *northwest wind* blows from the northwest. The velocity of the wind is determined by an *anemom'eter*, which consists of a small vane having fans, which the wind turns, the number of turns in a given time showing the velocity.

The velocity of a moderate wind is from 13 to 22 feet in a second; of a fresh breeze, from 22 to 36 feet; of a strong wind, from 36 to 56 feet; of a gale, from 56 to 90 feet; and of a hurricane, from 90 to 120 feet a second, or from 65 to 82 miles an hour.

400. **Winds are caused** by a difference of temperature between adjacent countries. The air in contact with the heated surface of the earth rises and flows toward the colder regions, while the lower strata of air in those regions flow toward the warmer parts, to supply the place of the heated air. Thus are produced two winds—an upper one blowing from the heated region, and a lower one blowing toward it.

401. **Winds are classed** as regular, periodical, and variable winds. *Regular winds* blow all the year from the same quarter; these are the *trade winds*. *Periodical* winds are those that blow in the same direction at the same seasons of the year, or at the same hours in the day; such are the *monsoons* and the *land and sea breezes*.

Variable winds are those which constantly change their direction. This is the general character of the winds of the temperate zones.

The *trade winds* generally blow from the northeast on the north side of the equator, and from the southeast on the south side of the equator. They prevail between the equator and 30° of north and south latitude. They are caused by the action of the sun upon the equatorial regions, causing currents to set in from the poles to the equator, which are deflected toward the west by the eastward rotation of the earth.

The *monsoons* (from an Arabic word signifying *season*) are winds which blow for one-half of the year in one direction, and the other half in another. They prevail chiefly in the Indian Ocean and some of its tributary seas, gulfs, and bays, blowing toward the continents in summer and away from them in winter. They are caused by the inequality of heat in different parts of the earth. While the sun is north of the equator—from March 21st to September 23d—the northern part of Africa and the southern part of Asia are heated to a higher degree than the Indian Ocean and South Africa and Australia. Hence the general direction of the wind is from the south, but it is deflected toward the west in the same manner as the trade winds. In the other half of the year this is reversed, as the heat passes from Asia and Africa to the Indian Ocean and Australia.

Land and sea breezes prevail on the sea-coast and on islands in tropical climates. They derive their name from the fact that they blow from the sea toward the land during the day—from a short time after sunrise to 3 or 4 o'clock in the afternoon—and the remainder of the twenty-four hours from the land toward the sea. In the morning, as the land becomes heated more rapidly than the water, the air over the former rises, and thus causes currents from the sea; and in the evening the land cools sooner than the water, and thus disturbs the equilibrium of pressure in the reverse manner.

402. **Atmospheric pressure** influences the direction of the wind, which invariably blows from the place of higher pressure to that of lower.

The wind blows round the area in which the pressure is increased or diminished, the direction being the same as that of the hands of a watch, when the pressure is higher, and in the contrary direction when it is lower. The latter circulatory movement, when extremely violent, causes the cyclone or West Indian hurricane.

The law of direction for places in the northern hemisphere, independently of the effect of local configuration—as of mountains and valleys—has been simply stated as follows: If we stand with our back to the wind, the line of lower pressure will be on the left hand. In the southern hemisphere it would be on the right hand.

The diversities of atmospheric pressure, and the conditions which they denote, render the barometer a most important instrument in weather prognostications. The indications of low pressure on the barometer are usually marked by the words *Stormy*, *Much Rain*, and *Rain;* and the contrary, *Very Dry*, *Set Fair*,

and *Fair*. But these are by no means invariably correct; in fact, they are often very deceptive.

Weather charts show the barometric pressure,* the temperature of the air, and the force and direction of the wind, for large areas; and from these data, predictions of the weather are made.

403. **Fogs and mists** are partly condensed vapors resting on the surface of the earth. When the surface of the ground is warmer than the air above it, the vapors become condensed as they arise, and appear as fog or mist. A fog is merely a thick mist.



Fig. 290.

404. **Clouds** are masses of condensed vapor floating in the atmosphere. Their varying appearance gives rise to their classification into four kinds: the *nimbus*, the *stratus*, the *cumulus*, and the *cirrus*.

These four kinds of cloud are respectively represented in Fig. 290, being marked by one, two, three, and four birds on the wing. The *cirrus* is com-

* "A low barometer is not a reliable sign of wet or stormy weather, neither is a high barometer to be depended upon for expecting fine weather. A sudden and considerable fall is an almost certain indication of stormy winds and stormy weather. The least reliable of all the barometric changes is a sudden rise. In winter it may be followed by hard and sudden frost, in summer by sultry weather and thunder-storms. All that may be safely said of such sudden rise is, that it indicates a change of some sort."—*W. M. Williams.*

posed of small whitish clouds which present a thin fibrous or fleecy appearance. Such clouds occupy the higher regions of the atmosphere. The *cumulus* consists of white masses of cloud, resembling mountains piled one on the other.* The *stratus* has the form of horizontal sheets or layers; and the *nimbus* is a dark rain-cloud.

These different forms are often combined, and form clouds of various appearances, to which the compound terms *cirro-cumulus*, *cirro-stratus*, and *cumulo-stratus* have been given.

The mean height of clouds is about 4,000 feet in winter, and 12,000 feet in summer. The height often greatly exceeds this. Gay-Lussac, in his balloon, observed cirrus clouds above him, while he was at a height of nearly 23,000 feet.

405. **Rain** is caused by a complete condensation of the clouds in the atmosphere, the aqueous vapor being changed into water, which falls in drops to the earth.

The difference between rain and fog or mist consists in the size of the drops. The vesicles of vapor in the latter are exceedingly small—in fog too minute to be distinguishable. Rain is formed by the union of these vesicles.

The *rain gauge* (Fig. 291) is an instrument designed to show the quantity of rain that falls in any given time or place. It is a cylindrical vessel, M (Fig. 292), closed at the top by a funnel-shaped lid, in which there is a small hole, through which the rain-water runs into the vessel. The water rises in the glass tube A, connected with the lower part of the vessel, and shows by a scale the height of the water inside. Thus, a height of two inches in the glass would indicate a rainfall, for the particular time, of two inches.



Fig. 291.



Fig. 292.

In general, the greatest annual rainfall occurs in tropical or hot regions, since the vaporization there is most abundant. At London, it is 23.5 inches; at Madeira, 27.7; at Bombay, 84.7; at Havana, 91.2; at St. Domingo, 107.6; at Balize, 153.0. The greatest annual rainfall is at Cherrapongee, in northern India, where it is 610.3 inches, more than 500 inches of which fall during seven months.

An inch of rain on a square yard of surface is equivalent to a fall of 46.74 pounds, or 4.67 gallons; which, in round numbers, is the same as 100 *tons per inch per acre.*

* "Cumuli are the heads of columnar bodies of vapor, which rise from the earth's surface, and are precipitated as soon as they reach a certain elevation. Thus the visible cloud forms the capital of an invisible pillar of saturated air."—*Tyndall.*

406. **Water-spouts** are great whirling masses, or columns, of vapor, moving with great force and rapidity over the surface of the earth, usually over the sea, and connecting with the clouds in the higher regions of the atmosphere.

Water-spouts revolve at their base with force enough to destroy houses and uproot trees, and are generally accompanied by rain and hail, often emitting lightning and causing thunder. As they pass over the sea, the water is violently agitated, and rises in the form of a cone, while the clouds descend in a similar

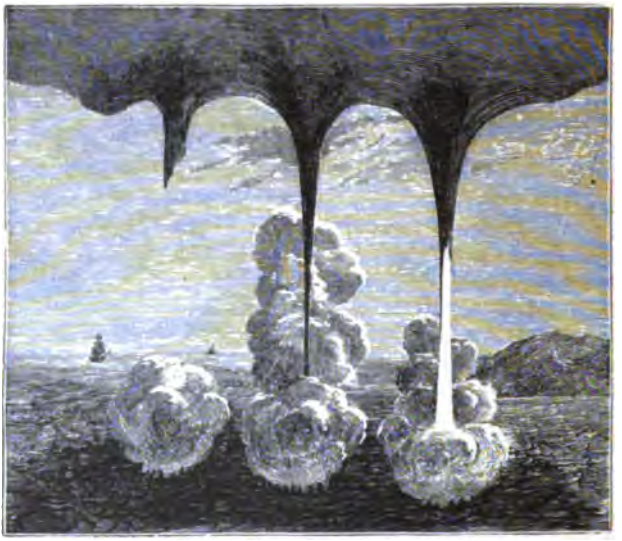


Fig. 293.

form to meet the spout (Fig. 293). But, even on the ocean, the water of the spout is not salt, which shows that it is formed of condensed vapor, not of sea-water. No fully satisfactory explanation of this phenomenon has yet been given.

407. The aqueous vapors of the atmosphere possess the property of absorbing and radiating heat in a very high degree.

Tyndall has demonstrated, by a series of interesting experiments, this remarkable property of aqueous vapor; in connection with which he remarks: "Regarding the earth as a source of radiant heat, no doubt, at least ten per cent. of its heat is intercepted within ten feet of the surface." That is, it is absorbed by the aqueous vapors. The power of absorption and radiation possessed by aqueous vapor is said to be more than 16,000 times that of the air.

To this radiation is attributed the copious rains of tropical climates; for when

the warm vapors reach the dryer portions of the atmosphere, they rapidly radiate their heat, and thus become condensed, descending in torrents to the earth. The aqueous vapors near the earth absorb its heat, but are prevented from radiating it by the vapors above. In dry regions, the terrestrial radiation is very rapid; and hence their daily extremes of temperature are enormous. In the interior of Australia, a difference, within twenty-four hours, of 40° C. has been recorded. In India and the Desert of Sahara, ice has been formed at night in consequence of excessive radiation of the terrestrial heat. But this, ordinarily, is prevented by the presence of copious vapors, which act, to use the illustration of Tyndall, "as a blanket more necessary to vegetable life than clothing is to man." The blue color of the sky has also been attributed to the presence of aqueous vapor.*

408. **Dew** is formed by the condensation of the aqueous vapor of the air coming in contact with a cold surface.

In clear nights, the deposition of dew is most copious, because then the terrestrial radiation is most rapid; but clouds in the atmosphere radiate heat to the earth, and thus by checking its loss of heat, prevent the formation of dew. A strong wind greatly diminishes the deposition of dew, because it does not give the air time to become cooled; but a light wind, by renewing the supply of saturated air, increases the formation. Of course, dew is most copiously formed on bodies which radiate most readily, such as the leaves of vegetables. Thus, by a wise provision of Nature, dew is supplied where it is most needed, and in hot countries becomes a sustainer of vegetation. Moreover, when the plants are thus covered with moisture, which is a non-conductor, they are prevented from further radiation, and are thus protected from severe cold.

409. **Hoar frost** is aqueous vapor frozen by being deposited on bodies, the temperature of which is below the freezing-point. These vapors freeze before they become dew.

410. **Snow** is aqueous vapor frozen in the atmosphere, in beautiful star-shaped crystals of various forms.

Some of these snow-crystals highly magnified are represented in Fig. 294. When formed in a calm atmosphere, they are more regular than when there is a great degree of disturbance.

When the aqueous vapor of the clouds is frozen after a greater degree of condensation, it forms *sleet*, which has the form of small needles of ice pressed together in a confused mass.

411. **Hail** is formed from vapor condensed into rain-drops, and frozen in the higher and colder regions of the atmosphere. These

* "As far as I can judge, aqueous vapor and liquid water absorb the same class of rays. This is another way of stating that the color of pure water is shared by its vapor. In virtue of aqueous vapor, the atmosphere is therefore a blue medium."—*Tyndall.*

frozen drops collect into compact globules of ice, sometimes of considerable size, and descend with a rattling noise to the earth.

Hail occurs in the summer, at the hottest parts of the day; and hail-storms are the most severe in tropical countries. It generally precedes a thunder-storm, and sometimes accompanies it, but rarely, if ever, follows it. Hail-stones have usually the size of peas, but sometimes are as large as an egg or an orange; and accounts are given of storms in which masses of ice of still greater size have fallen.

This phenomenon is attributed by some to the sudden and violent disturbance of the equilibrium of the atmosphere, caused by the heated portions coming in contact with cold currents. The masses of vapor instantly condensed in



Fig. 294.

this way are carried to the colder regions of the air by the violence of the wind, and are frozen; and, at the same time, the electricity evolved acts upon the small ice-masses, giving them a whirling motion. These small hail-stones coming together unite, and thus form the larger masses.

412. Among the most striking of the luminous meteors, or atmospheric phenomena, is the *aurora borealis*, or northern light; sometimes, and more properly, called the *polar aurora*, as it is seen at both poles.

This brilliant and interesting phenomenon is often visible at a great distance from the poles, and over an immense area. The same display has been seen at Moscow, Warsaw, Rome, and Cadiz. Its height is variously estimated at from 90 to 460 miles. Its usual form is that of luminous clouds, with arches and rays (streamers) darting and flashing with great rapidity; the latter meeting sometimes at or near the zenith, and forming what is called the *boreal crown*. The arches are sometimes single; while at others several concentric ones are seen. A much rarer form is that in which the rays seem to hang from the sky like the folds of

a luminous curtain (Fig. 295). The color of the aurora varies, from white or very pale green to crimson, violet, or steel-color. In some countries these lights are called the "merry dancers," from the tremulous flashing of the streamers.

The occurrence is most frequent at the equinoxes, and least so at the solstices; and varies in frequency in different years, reaching a maximum every eleven years, which has been found to coincide with the period of the greatest number of sun-spots.

There are various hypotheses to account for this phenomenon, but none is entirely satisfactory. De la Rive attributes it to electric discharges which take place in the polar regions between the positive electricity of the atmosphere and the negative electricity of the earth. It has been ascertained, however, that an auroral display never occurs except at the time of magnetic disturbances; and,



Fig. 295.

according to Balfour Stewart, of England, it is due to magnetic currents caused by rapid changes in the earth's magnetism. He likens the earth to the magnetic core of a Ruhmkorff's coil (Art. 388), of which the lower strata of the atmosphere constitute the insulator, and the upper strata (which being rarer form an electrical conductor) form the secondary coil.

Lightning, with its accompaniment *thunder* (Art. 342), and the *rainbow* (Art. 288), are also to be regarded as atmospheric meteors.

413. **Climate** is a term used to denote the general peculiarities that characterize the atmosphere at any particular part of the earth's surface. That part of physics which treats of climate is called *climatology*.

By some, seven distinctions of climate are noted as dependent upon mean

annual temperature: (1) a *hot climate*—from 30° to 25° C.; (2) a *warm climate*—from 25° to 20° C.; (3) a *mild climate*—from 20° to 15° C.; (4) a *temperate climate*—from 15° to 10° C.; (5) a *cold climate*—from 10° to 5° C.; (6) a *very cold climate*—from 5° to 0° C.; (7) an *arctic climate*—below 0° C., or the freezing-point.

Climates are also classed as *constant*, *variable*, and *extreme*, dependent upon the difference between the mean annual temperature and the extreme of winter or summer. The climates of London and Paris, for example, are variable; those of New York and Pekin are extreme. Island climates are the least variable, because the temperature of the sea is constant.

Among the characteristics of climate are included the moisture of the air, the quantity and frequency of rains, the direction and intensity of prevailing winds, the number and severity of storms, and the nature of the soil. Sanitary conditions also give rise to the distinction between healthful and unhealthful climates.

414. **Registration of Phenomena.**—An instrument for the automatic registration of meteorological phenomena is called a *meteorograph*. It comprehends devices for registering the direction and velocity of the wind, the temperature of the air, the height of the barometer, and the fall of rain.

These are all recorded not only automatically, that is, by the unassisted action of the apparatus, but simultaneously. The movements of the meteorograph are regulated by clock-work, in connection with which a series of electro-magnets are employed, the motion of the armatures of which operate the pencils. Thus the passage of the current in one or another of these magnets is caused by the movement of a vane which is acted on by the wind, all changes in the direction of which are thus instantly registered. The expansion and contraction of wires, transmitted by a system of levers to a pencil, cause the latter to trace a curve line that shows the variations in the temperature of the air; and in a similar manner other atmospheric changes are accurately recorded.

SYNOPSIS FOR REVIEW.

METEOROLOGY.

1. *Definitions.*
 1. Meteorology.
 2. Meteors: 1. Aërial. 2. Aqueous. 3. Luminous.
2. *Winds.*
 1. Direction.
 2. Velocity.—Anemometer.
 3. Cause of winds.
 4. Classification:
 1. Regular.—Trade winds.
 2. Periodical: 1. Monsoons. 2. Land and sea breezes.
 3. Variable.
3. *Atmospheric Pressure.*
 1. Law of.
 2. Diversities of.
 3. Barometric indications: 1. Of low pressure. 2. Of high pressure.
 4. Effect on the winds.—Cyclone.
 5. Weather charts.
4. *Fogs and Mists.*
5. *Clouds.*
 1. Definition.
 2. Classification: 1. Cirrus. 2. Cumulus. 3. Stratus. 4. Nimbus. — Cirro-cumulus. Cirro-stratus. Cumulo-stratus.
 3. Mean height.
6. *Rain.*
 1. Cause.
 2. Rainfall: 1. Measure of.—Rain gauge. 2. Annual quantity at different places
7. *Water-spouts.*
8. *Absorption and Radiation of Heat by Aqueous Vapor.*
 1. Degree as compared with air.
 2. Effect of in tropical regions.
9. *Dew.*
 1. Cause.
 2. Effect on vegetation.
10. *Hoar Frost.*
11. *Snow.*—Crystals of snow.
12. *Hail.*
13. *Aurora Borealis*, or *Polar Aurora.*
 1. Appearance.
 2. Cause.
14. *Climate.*—Classification of.
15. *Registration of Phenomena.*

INDEX.

[THE NUMBERS REFER TO PAGES.]

ABERRATION, chromatic, 163; spherical, by reflection, 144; by refraction, 155
Absolute index of refraction, 147
Absorbent power, 123; of aqueous vapor, 252
Absorption, 252
Accelerated motion, 23
Achromatic lens, 163
Achromatism, 163
Aclinic lines, 193
Acoustic figures, 98
Acoustics, 85
Actinic rays, 159
Action and reaction, 17
Adhesion, 40; between solids and gases, 41
Aërial meteors, 248
Affinity, chemical, 40
Aggregation, states of, 10
Agonic line, 191
Air, resistance of, 36; composition of, 67; expansive force of, 68; weight of, 67, 73; velocity of sound in, 87; inductive capacity of, 201
Air-balloons, 74
Air-chamber, 81, 82
Air-pump, 76; rarefaction of air in, 78; uses of, 78
Alarm, electric, 234
Alcohol, specific gravity of, 57; boiling point of, 112, 118; index of refraction of, 147
Alcohol thermometer, 112
Alloys, 42, 116
Alum, diathermancy of, 123
Ampère, law of, 10 (note)
Analysis, spectrum, 162; by polarization, 182
Analyzer, 180, 182
Anamorphosis, 145
Aneroid barometer, 72
Angle, of refraction, 146; of deviation, 150, 165; critical, 147; polarizing, 180
Angles, of incidence and reflection, 88, 146
Animal electricity, 244
Animal heat, 131
Annealing, 42
Aperture, of a spherical mirror, 141
Apparatus, electrical, 202
Application, point of, 15; of the pendulum, 25
Aqueous humor, 174
Aqueous meteors, 248
Aqueous vapors, absorption and radiation of heat by, 252
Arc, voltaic, 224; sine of, 146 (note)
Archimedes, principle of, 53, 74
Areas, spaces, and times, relation of, 24
Argand lamp, 124
Armatures, 190
Armstrong's hydro-electric machine, 206
Artesian wells, 52
Artificial cold, greatest, 112

Artificial magnets, 186
Ascending bodies, 88
Ascent of liquids in capillary tubes, 57; between glass plates, 58
Astatic needle and system, 193
Astronomical refraction, 147
Astronomical telescope, 167
Athermancy, 123
Atmosphere, 67; composition of, 67; pressure of, 68; height of, 68; weight of, 69
Atmospheric phenomena, 248; registration of, 256
Atmospheric pressure, 70; effect on boiling point, 118; on direction of the wind, 249
Atomic theory, 10
Atomo-mechanical theory, 11 (note)
Atoms, 9
Attraction, molecular, 40; magnetic, 187; electric, 197
Atwood's machine, 37
Aurora borealis, 193, 254
Auscultation, 20
Austral pole, 186
Avogadro, law of, 10 (note)
Axis, of suspension, 36; secondary, 152

BALANCE, 36; torsion, 41, 188; compensation, 114
Balloons, 74
Barometer, 70; cistern, 70; siphon, 70; wheel, 71; aneroid, 72; weather changes, how marked on, 249
Baroscope, 74
Battery, magnetic, 189; electric, 211; voltaic, 221; Wollaston's, 221; Daniell's, 222; Grove's, 222; Bunsen's, 222; Smee's, 223; relay, 233; thermo-electric, 243
Bellows, 92
Biot, experiments of, 88
Black's calorimeter, 125
Block and tackle, 20
Blood heat, 113
Bodies, properties of, 11
Body, 9; of screw, 23
Boiler, 126
Boiling, 117; effect of pressure on, 118
Boiling-point, 118
Boreal crown, 254
Boreal pole, 186
Boyle's law, 73
Bramah's press, 51
Brass, specific gravity of, 56
Breaking weight, 41
Breast-wheel, 61
Brewster, Sir David, inventor of the kaleidoscope, 139
Brittleness, 42
Brush discharge, 213
Bunsen's battery, 222

CALIBRATION, 112
Calorescence, 162
Calorific rays, 159
Calorimeter, 125
Calorimetry, 125
Camera obscura, 172
Capella, spectrum of, 161
Capillary attraction, 57; phenomena of, 59
Carbon, infusibility of, 224
Carbon battery, 222
Carbon points, 224; projection of, 225
Carbonic acid in the air, 67
Carpenter, Prof., 245
Cartesian diver, 54
Cast-steel, tenacity of, 41
Catalani's voice, 105
Catoptric telescope, 169
Catoptrics, 138
Caustics, by reflection, 144; by refraction, 155
Cavendish, 33 (note)
Center, of oscillation and suspension, 25; of gravity, 33; optical, 152
Centigrade scale, 112
Centrifugal force, 24
Centripetal force, 24
Character (*timbre*) of musical sounds, 94
Charcoal, use of, for voltaic arc, 224

Charge of a Leyden jar, 210
Chemical affinity, 40
Chemical effects, of the electric discharge, 212; of a voltaic current, 225
Chemical rays, 159
Chemistry, object of, 9
Chimes, electrical, 207
Choroid, 174
Chromatic aberration, 163
Circle, motion in, 24
Circuit, galvanic, 219
Cirro-cumulus, 251
Cirro-stratus, 251
Cirrus, 251
Cistern barometer, 70
Clack valve, 80
Clarke's magneto-electric machine, 238
Climate, 255
Clouds, 250; mean height of, 251
Cochlea, 106
Co-efficient of expansion, 113; of liquids, 114
Clocks, how regulated by the pendulum, 25
Cohesion, 40
Coil, primary and secondary, 235; induction, 239; Ruhmkorff's, 239
Cold, sensation of, 121
Collision of bodies, 26
Color, 11; of bodies, 158
Colored rings, 182
Colorific rays, 159
Colors, 156; complementary, 159; of thin plates, 178
Combustion, 131
Comma, musical, 95
Communicator, or key, 233
Compass, Mariner's, 192
of the human voice, 105 (note)
Compensation balance, 114
Compensation pendulum, 114
Complementary colors, 159
Component forces, 15
Composition of light, 155
Compound microscope, 165
Compressibility, 13; of gases, 67
Concave lenses, 154
Concave mirrors, 141; virtual image of, 143
Condenser, of steam-engine, 128; electrical, 208; Epinus's, 209
Condensing engine, 129
Conduction of heat, 120
Conductors and non-conductors, 196
Congelation, 116
Conical mirrors, 145
Conical valve, 80
Conjugate foci, of mirrors, 141; of lenses, 152
Conservation of energy, 28
Constant battery, 121
Constant climate, 256
Continuous spectrum, 160
Contractile force, 113
Convection of heat, 120
Convergent rays, 135
Convex lenses, 151; optical center of, 152; image formed by, 153
Convex mirrors, 143
Copper, specific gravity of, 56
Cork, specific gravity of, 56
Cornea, 174
Corpuscular theory, 134
Corti's fibers, 106
Coulomb's torsion balance, 188
law of electrical attraction, 198
Couple, voltaic, 219; thermo-electric, 243
Cowper's writing telegraph, 234
Critical angle, 148
Crookes's radiometer, 124
Crown-glass, 152 (note)
Crystalline lens, 174
Crystallization, 116; exhibition of, 174
Cubical expansion, 110, 113
Cumulo-stratus, 251
Cumulus, 251
Cupping, 70
Current, voltaic, 220; direct and inverse, 236

Curved mirrors, 140
Curves, magnetic, 189
Cut-out, 234
Cylinder, of steam-engine, 127
Cylinder machine, 204
Cylindrical mirrors, 145

DANIELL'S pyrometer, 112; battery, 222; hygrometer, 119
Dark lines of the spectrum, 160
Declination of the magnetic needle, 191
Decomposition of water, 225
Density, of the earth, 33; of a gas, 115; electric, 199
Deviation, angle of, 165
Dew, 120, 253
Dew point, 119
Diamond, hardness of, 42; specific gravity of, 56; index of refraction of, 147
Diaphanous bodies, 134
Diathermancy, 123
Diatonic scale, 95
Dielectric polarization, 201
Dielectrics, 201
Diffraction, 177; bands, 178; spectra, 178
Diffused light, 140
Diffusion of heat, 122; of liquids, 61
Diosmose, 60
Dip of magnetic needle, 192
Direct vision spectroscope, 162
Disc, Newton's, 158
Discharge, electric, 212
Discharging rods, 210
Dispersion of light, 156
Dispersion of power, 156
Distillation, 118
Divergent rays, 135
Divisibility, 12
Dolland's chromatic lens, 163
Dot and dash alphabet, 232
Double-action steam-engine, 127
Double refraction, 146, 176
Ductility, 42
Duration of electric spark, 215
Dynamical electricity, 218
Dynamo-electric machines, 238

EAR, the, 105
Earth, orbital velocity of, 14; mean density of, 33; shape of, 40; magnetic poles of, 191
Ear-trumpet, 90
Ebullition, 117
Echoes, 89
Edison's phonograph, 104
Efflux, velocity of, 62
Elastic balls, collision of, 27
Elastic fluids, 66
Elasticity, 13; of solids, 41; of traction and fissure, 41
Electric alarm, 234; pendulum, 195; attraction, 197; density, 199; spark, 207; battery, 211; discharge, 212; egg, 213; pistol, 215; light, 224; telegraph, 231
Electrical attraction and repulsion, 197
chimes, 207
fish, 244
induction, 199
machine, 202
potential, 212
whirl or vane, 207
Electricity, frictional, 195; resinous and vitreous, 196; positive and negative, 197; distribution of, 198; accumulation of, 199; communication of, 201; loss of, in machine, 204; velocity of, 215; galvanic or dynamical, 218; animal, 244
Electrodes, 221
Electro-dynamics, 229
Electro-gilding, 227
Electrolysis, 226
Electrolyte, 226
Electro-magnetic engines, 235
Electro-magnetism, 228
Electro-magnets, 230
Electro-metallurgy, 226
Electrometer, 204
Electro-motive force, 220

Electro-motive series, 220
Electro-motors, 235
Electrophorus, 208
Electro-plating, 227
Electroscope, 195; gold-leaf, 202
Electro-silvering, 227
Electro-statics, 229
Electrotypy, 226
Elements, 9
Emission, theory of, 109
Endosmometer, 60
Endosmose and exosmose, 60
Energy, 27; transformation of, 28; conservation of, 28
Engine, steam, 126; double action, 127
Epinus's condenser, 209
Equator, magnetic, 193
Equilibrium, 34; of liquids, 49
Erecting eye-piece, 171
Escapement, 26
Essential properties, 11
Ether, universal, 11
Ether waves, length of, 156; number of, 156
Evaporation, 117
Exosmose, 60
Expansion, by heat, 113; co-efficient of, 113; of liquids, 114; of gases, 115; force of, 115
Express train, velocity of, 14
Extension, 12
Extraordinary ray, 176
Extreme climates, 256
Eye, the human, 174
Eye-piece, of the microscope, 165; of the telescope, 167

FAHRENHEIT'S scale, 112
Falling bodies, 36; laws of, 37
Faraday, 226, 236, 237, 245
Fata Morgana, 149
Field, magnetic, 189
Finder of telescope, 169
Fire-engine, 82
Fish, electrical, 244
Fixed liquids, 117
Fixed pulley, 19
Fizeau's method, 137
Flame, 131
Flames, effect of sound on, 101; sensitive, 102; illuminating power of, 131
Flexure, elasticity of,
Flint-glass, 152; specific gravity of, 56
Floating bodies, 54
Florentine experiment, 12
Fluid, 10
Fluids, magnetic, 187
Fluorescence, 163
Fluor spar, diathermancy of, 124
Fly-wheel, 13
Focal distance, 151
Focus, principal, 141; real and virtual, 141; conjugate, 141
Focusing, 167
Fogs, 250
Foot-pound, 27
Force, 14; constant and variable, 15; centripetal and centrifugal, 24; impulsive, 26
Forces, resultant of, 14; parallelogram of, 16
Foucault's method, of finding velocity of light, 137; of projecting carbon points, 224
Fountain in vacuo, 78
Franklin's experiment, 201 (note)
Fraunhofer's lines, 159
Freezing mixture, 113
Freezing point, 112
French unit of work, 27
Friction, 23; a source of heat, 129
Friction wheels, 37
Frictional electricity, 195
Fulcrum, 18
Fundamental color, 159; note, 95
Fusion, 116

GALILEO'S discovery of the laws of falling bodies, 37
Galileo's telescope, 171
Galvani, experiments of, 218, 244

Galvanic circuit, 219
Galvanism, 218
Galvanometer, 228
Gas, specific gravity of, 115
Gaseous state, 10
Gases, 10; fluidity of, 45; elastic force of, 66; expansibility of, 66; compressibility of, 67, 73; weight of, 73; expansion of, 115
Gay-Lussac, balloon ascension by, 74, 251
Gay-Lussac's barometer, 71
Geissler's tubes, 240
General properties of matter, 11
Gilbert, Dr., 195
Glaisher's balloon ascension, 75
Glass, crown, 152; flint, 152; index of refraction of, 147; unannealed, 176
Gold, porosity of, 12; malleability of, 42; specific gravity of, 56; fusing point of, 116
Gold-leaf electroscope, 202
Governor, 128
Graham's mercury pendulum, 114
Graphic method of determining the number of vibrations, 93
Gravitation, universal, 32
Gravity, 33; center of, 33; specific, 55
Gregorian telescope, 169
Gridiron pendulum, 113
Grindstones, tendency to burst, 24
Grove battery, 222
Guericke, Otto von, 76
Gymnotus, 245

HAIL, 253
Hailstones, size of, 254
Hardness, 42
Harmonics, 96; in human voice, 105
Heat, 109; mechanical theory of, 109; general effects of, 110; external and internal work of, 110; latent, 116; radiation of, 120; conduction of, 120; convection of, 120; radiant, 121; absorption of, 122; reflection of, 122; specific, 125; sources of, 129; terrestrial, 130; animal, 131
Heating, effects of, on a magnet, 190; on the electric discharge, 213; on the voltaic current, 223
Heat rays, 159; polarization of, 182
Height of barometric column, 71
Heights, determination of by the barometer, 72
Heliograph, 140
Helix, 230
Helmholtz, 130 (note)
Hemispheres, Magdeburg, 69
Henry, Prof., 235
Hero's Fountain, 79
Herschel's telescope, 170
High pressure steam-engine, 129
Hill battery, 222
Hoar frost, 253
Holtz's electrical machine, 205
Homogeneous medium, 135
Hooke, 32
Hughes's microphone, 241
Human, ear, 105; voice, 105; eye, 174
Humboldt, 193, 245
Hurricane, velocity of, 14
Huyghens, 134, 176, 179
Hydraulic press, 50
Hydraulics, 45
Hydro-dynamics, 45
Hydro-electric machine, 206
Hydrogen flame, 131
Hydrogen gas, density of, 87
Hydrometer, 56
Hydrostatic balance, 56
bellows, 47
paradox, 48
Hydrostatics, 45
Hygrometer, 119
Hygrometric state, 119
Hypothesis, 11

ICE, melting-point of, 116; force produced by the formation of, 117; diathermancy of, 123
Ice calorimeter, 125

Iceland spar, double refraction of, 176; polarization by, 179
Illuminating power of flames, 131
Image, formation of in concave mirrors, 142; real and virtual, 142; in convex mirrors, 144; by a convex lens, 153; by a concave lens, 154
Impact, 26
Impenetrability, 12
Impulsive force, 26
Incidence, angle of, 138, 146
Incident ray, 146
Inclination of magnetic needle, 192
Inclined plane, 21
Index of refraction, 146; absolute and relative, 147
Indicator, 231
Induced currents, 235; produced by the action of magnet, 236; properties of, 237
Induction, electrical, 199; magnetic, 188; voltaic, 234
Induction coil, 239
Inductive capacity, 201
power, 201
Inertia, 14
Insulating stool, 207
Insulation, 196
Insulators, 196
Intensity, of sound, 86; of musical sounds, 94; of light, 137; of terrestrial magnetism, 193; of electricity, 223
Interference, of sound 98; of light, 176
Intervals, musical, 95
Iris, 174
Iron, specific gravity of, 56; expansion, of, 113; melting point of, 113; reflection of heat by, 122; radiating power of, 122; used for the electromagnet, 231
Irradiation of, 176
Irregular reflection, 140
Isoclinic lines, 193
Isodynamic lines, 193
Isogonic lines, 191
Ivory, specific gravity of, 56

JACOBI, Prof., 226
Jar, Leyden, 210; with movable coatings, 211
Jets, 62
Jupiter, eclipse of the satellites of, 136

KALEIDOSCOPE, 139
Keepers, 190
Kepler, 32 (note)
Key of electric telegraph, 233
Knife edge, 36
Kirchhoff, experiments of, in spectrum analysis, 162; to ascertain the velocity of electricity, 215
Koenig's apparatus, 103

LABYRINTH of the ear, 106
Land and sea breezes, 249
Lantern, magic, 173
Laryngoscope, 145
Latent heat, 116; of fusion, 126; of vaporization, 126
Law, physical, 10
Layer of constant temperature, 130
Lead, specific gravity of, 56
Lenses, 150; kinds of, 151; focus of, 151; principal axis of, 151; convex, 151; concave, 154
Level, water, 51; spirit, 52
Lever, 18; compound, 19
Leyden jar, 210
Light, 134; propagation of, 134; velocity of, 136; intensity of, 137; reflection of, 138; refraction of, 146; composition of, 155; dispersion of, 155; interference of, 176; polarization of, 179; electric, 224
Lightning, 201
Lightning arrester, 234
Line, of direction, 34; of no variation, 191
Line spectrum, 160
Linear expansion, 110

Liquids, 10; compressibility of, 45; elasticity of, 46; equilibrium of, 49; free surface of, 59; diffusion of, 61; expansion of, 111; diathermancy of, 123
Locatelli's lamp, 123
Locomotive, 129
Lodestone, 186
Long sight, 175
Loops, 96
Low pressure engines, 129
Lubber's point, 192
Luminiferous ether, 134
Luminous bodies, 134
Luminous effects, of electric discharge, 212; of the voltaic current, 224
Luminous meteors, 248
pane, 213
ray, 134
tube, 213

MACHINE, 18; Atwood's, 37; electrical, 202; dynamo-electric, 238; Spottiswoode's, 240
Machines, simple, 17
Magdeburg hemispheres, 69
Magic lantern, 173
Magnetic attraction and repulsion, 187; law of, 188
battery, 189
curves, 189
effects of electric discharge, 212
equator, 193
field, 189; production of electric currents in, 237
fluids, 187
force, 190
induction, 188
intensity, point of least, 193
needle, declination of, 191; inclination of, 192
phenomena, 193
poles of the earth, 191
storms, 193
substances, 188
Magnetism, 186; red and blue, 187; terrestrial, 191
Magnetization, 190; effect on volume, 231
Magneto-electric machine, 238
Magneto-electrical induction, 237
Magneto-electricity, 237
Magnets, artificial and natural, 186; properties of, 186; poles of, 186; temporary and permanent, 188; action of on voltaic currents, 229
Magnifying power, of a microscope, 167; of a telescope, 169
Main line sounder, 234
Major scale, 95
Major tones, 95
Malleability, 42
Malus, 179
Mariner's compass, 192
Mariotte's law, 73
Marked end of the magnets, 191
Maskelyne, Dr., 33
Mass, 11 (note), 39
Matter, 9; essential attributes of, 11
Mechanical effects of electric discharge, 212
Mechanical philosophy, 9
powers, 17
Medium, 135; of parallel faces, 149
Melloni's experiments, 123
Melting point of various substances, 116
Membranes, vibrations of, 98
Meniscus, 151
Mercurial thermometer, 111
Mercury, specific gravity of, 57; boiling point of, 112, 113; solidification of, 112; use of, in the pendulum, 114; expansion of, 114; fusing-point of, 116
Merry Dancers, 255
Metallic mirrors, 139
Metals, discovery of by spectrum, 162; conductivity of, 196
Meteorograph, 256
Meteorology, 248
Meteors, 248

Microphone, 241
Microscope, 165; compound, 165; magnifying power of, 167; solar, 174
Minor tones, 95
Mirage, 148
Mirrors, 138; plane, 138; curved, 140; concave, 141; convex, 143; parabolic, 145; cylindrical and conical, 145
Mists, 250
Mobility, 13
Molecular attraction, 40
forces, 9
motion, 109
Molecules, 9; distance between adjacent, 10; of liquids, 45
Momentum, 14
Mongolfier's balloon, 74
Monochord, 94
Monsoons, 249
Morse's alphabet, 232
telegraph, 231
Motion, 13; uniform, 14; rectilinear and curvilinear, 14; uniformly accelerated, 23; in a circle, 24
Movable pulley, 20
Multiple echoes, 89
images, 139
Muscular currents, 244
Music, 85; physical theory of, 93
Musical scale, 95
Musical sounds, 93; how produced, 94
Musk, divisibility of, 12
Myopy, 175

NAIRNE'S electrical machine, 204
Natural philosophy, 9
Needle, magnetic, 191, 192; astatic, 193
Negative electricity, 197
Neutral equilibrium, 34
line, 187
Newton, Sir Isaac, 26, 32, 134, 156 (note), 178
Newtonian telescope, 170
Newton's disc, 158
first law of motion, 13
Newton's rings, 178
theory of light, 134
Nicholson's hydrometer, 56
Nimbus, 251
Nobili's thermo-electric pile, 244
Nodes, 96
Noises and musical sounds, 85
Norremberg's apparatus, 181
Northern light, 254
North-pointing pole of magnet, 191
Notes, musical, 95
Nut of screw, 23

OBJECT-GLASS, 165; of telescope, 167
Octave, 95
Oersted, 228
Ohm's law, 223
Opaque bodies, 134
Opera-glass, 172
Ophthalmoscope, 145
Optical center, 152
instruments, 165
Optic nerve, 174
Optics, 134
Ordinary ray, 176
Organ pipes, 97
Oscillation, center of, 25
Overshot wheels, 61
Oxidation, 131

PAGE, Prof., 235
Pallets, 26
Pane, luminous, 213
Parabolic mirrors, 145
Parachute, 76
Paradox, hydrostatic, 48
Parallelogram of forces, 16
Parallel rays, 141, 151
Pascal, 51
Pascal's law, 46
Path of a projectile, 39
Pencil of light, 134
Pendulum, 25; simple and compound, 25; length of, 25; compensation, 113; gridiron, 113; electric, 195

Penumbra, 136
Percussion, a source of heat, 130
Periodical winds, 248
Periscopic glasses, 175
Permanent magnets, 188
Petroleum, specific gravity of, 57
Phenomena, physical, 9
Phial of four elements, 50
Phonautograph, 99
Phonograph, 104
Phosphorus, fusing point of, 116
Photographic camera, 172
Photometer, 137
Physical agents, 11
law, 10
phenomena, 9
theory, 11
Physics, object of, 9
Physiological effects, of the electric discharge, 212; of voltaic currents, 223
Piezometer, 45
Pigment colors, 159
Pile, voltaic, 219; thermo-electric, 243; Nobili's, 244
Pipes, organ, 97
Pisa, leaning tower of, 34
Pistol, electric, 215
Piston, 80
Pitch of musical sounds, 94
Pith-ball pendulum, 195
Plants, growth of, 159
Plate electrical machine, 202
Plates, colors of thin, 178
Plates, vibrations of, 97, 98
Platinum, ductility of, 42; specific gravity of, 56; fusing point of, 116
Plumb line, 33
Pneumatic syringe, 66, 130
Pneumatics, 66
Point of application, 15
Polariscope, 180
Polarity of magnet, 187
Polarization, of light, 179; by refraction, 179; by reflection, 180; dielectric, 201
Polarizer, 180, 182
Polarizing angle, 180, 181
Poles, of a magnet, 186; of a voltaic battery, 221; of a helix, 230
Polyprism, 150
Pores, sensible and physical, 12
Porosity, 12
Positive electricity, 197
Postal battery, 234
Potential, electrical, 212
Poundal, 15
Power, relation of, to weight, 18
Powder ram, 130
Press, hydraulic, 50
Pressure, on liquids, 46; on the side of a vessel, 48; atmospheric, 68, 249; upon bodies in air, 74; influence of, on boiling point, 117, 118
Priestley, Dr., 214
Primary coil, 235
Principal axis of a mirror, 141; of a lens, 151
focus of a mirror, 141; of a lens, 151
Principle of Archimedes, 53, 74
Prism, 149; right-angled, 150; achromatic, 164
Prisms, refraction by, 149
Projectiles, 38; path of, 39
Proof-plane, 198
Properties of bodies, 11
Pulley, 19; movable, 20
Pump, air, 76; suction, or lift, 80; suction and force, 80
Pumps, 79
Pupil, 174
Pyro-heliometer, 130
Pyrometer, 112
Pyronomics, 109
Pythagoras, 95 (note)

QUARTZ, diathermancy of, 123; polarizing angle for, 181

RADIANT heat, 121
Radiation, of heat, 120; laws of,

121; by polished surfaces, 123; of aqueous vapor, 252
Radiometer, 124
Rain, 251
Rain gauge, 251
Rainbow, 164
Rainfall, 251
Range, or random, 38
Ray, incident, 146; luminous, 134; ordinary and extraordinary, 176
Rays, actinic, 159; convergent and divergent, 135; of heat, 159; parallel, 151
Reaction, 17
Real focus, 141; image, 142
Reaumur's scale, 112
Receiver of air-pump, 76
Recomposition of white light, 157
Rectilinear motion, 23
Reed, 97; instruments, 97; pipe, 97
Reflected light, 140
Reflecting telescope, 169
Reflection, of sound, 88; of heat, 122; of light, 138; regular and irregular, 140; total, 147
Refracting angle, 149
telescope, 168
Refraction, 146; how caused, 146 (note); angle of, 146; index of, 146; double, 146, 176; phenomena of, 147; astronomical, 147; by prisms, 149; polarization by, 179
Refractory substances, 116
Refrangibility of rays, 156
Regular winds, 248
Relay battery, 233
Repulsion, true test of a magnet, 188
Resinous electricity, 196
Resonance, 89
Resultant of forces, 15, 17
Retina, 174
Return shock, 202
Right-angled prism, 150
Rings, Newton's, 178; colored, 182
Rock salt, diathermancy of, 124
Roemer, 136
Rolling friction, 23
Rosse's telescope, 170
Rotation of a magnet, 236
Ruhmkorff's coil, 239
Rumford, 110 (note)

SACCHARIMETER, 182
Safety valve, 127
whistle, 127
Saturation, degree of, 119
Savart's toothed wheel, 91
Scale, musical, 95
Scales, thermometric, 112
Sclerotica, 174
Scott's phonautograph, 99
Screw, 22
Sea-water, pressure of, 48; specific gravity of, 57
Secchi, classification of stellar spectra by, 160
Secondary axis of a mirror, 142; of a lens, 152
coil, 235
Seebeck, Prof., experiment by, 243
Semi-conductors, 196
Semitones, 95
Sensation of heat and cold, 121
Sensible heat, 126
Sensitive flames, 102
Shadow, 135
Sheave, of pulley, 19
Short sight, 175
Silver, specific gravity of, 56; melting point of, 113
Simple galvanic circuit, 219
microscope, 165
Sine, of an arc or angle, 146 (note)
Singing flames, 101
Siphon, 79; barometer, 70
Sirene, 91
Sleet, 253
Sliding friction, 23
Smee's battery, 223
Snow, 253; crystals, 253
Soap-bubbles, colors of, 178
Sodium, spectrum of, 160

Solar heat, 130
microscope, 174
radiation, 130
spectrum, 156; colors of, 156; rays of, 159; dark lines in, 159
Solidification, 116
Solids, 10
Solution, 116
Sonometer, 94
Sonorous bodies, 85
Sound, 85; cause of, 85; intensity of, 86; laws of, 86, 87; propagation of, 86; velocity of, in air, 87; in water, 88; in iron, 88; reflection of, 88; interference of, 98; effect of, on flames, 101
Sound vibrations, measurement of, 90; graphic method of determining, 93; in strings, 95
Sounder, 233
Sounds, visual representation of, 98; perception of, 105
Spark, electric, 207
Speaking-trumpet, 90
Speaking-tubes, 87
Specific gravities, table of, 56
Specific gravity, 55; of solids, 56; of liquids, 57; of gases, 115
Specific heat, 125
Specific properties, 11; of solids, 41
Spectra, different kinds, 160; diffraction, 178
Spectral colors, 159
Spectroscope, 161
Spectrum, solar, 155; of artificial light, 156; continuous and line, 160; analysis, 162
Speculoid reflection, 140
Spencer, Thomas, 226
Spherical aberration, 144; by refraction, 155
Spiral or helix, 230
Spirit level, 52
Spottiswoode's machine, 240
Stable equilibrium, 34
Standard of specific gravity, 55
Stars, spectra of, 160
Steam-engine, 126
Steel, tempering of, 40
Steeling, 227
Steinheil's telegraph, 231
Stereopticon, 175
Stereoscope, 175
Stethoscope, 90
Still, 118
Stirrup, of pulley, 19
Stool, insulating, 207
Storms, magnetic, 193
Stratus, 251
Strings, vibrations of, 94
Submarine cables, 215
Suction pumps, 81
Sulphur, specific gravity of 56; fusing point of, 116
Sun, heat of, 130 (note)
Sun-spots, 193, 255
Superficial expansion, 110
Suspension, center of, 25; axis of, 36
Swimming, 54
Swimming-bladder, 54
Symmes's theory, 197
Syringe, pneumatic, 66, 130

TASIMETER, 242
Telegraph, electric, 231; Morse's, 231; Steinheil's, 231; Wheatstone's, 231; Cowper's writing, 234
Telephone, 240
Telescope, 167; refracting, 168; reflecting, 169; Gregorian, 168; Newtonian, 170; Herschel's and Lord Rosse's, 170; terrestrial, 171; Galileo's, 171
Temperature, 111; required for ebullition, 117; effect of, on magnets, 190
Temperatures, table of, 112
Tempering, 42
Tenacity, 41; dependent on form, 42
Tension of gases, 66
Terrestrial gravitation, 33
heat, 130

Terrestrial magnetism, 191; intensity of, 193; action of, in induction, 237
telescope, 171
Thales, 195
Thallium, discovery of, 162
Theory, atomic, 10; physical, 11; of music, 93; of heat, 109; of light, 134, 180; of electricity, 197; of galvanism, 219
Thermal rays, 122
Thermal unit, 125
Thermo-electric battery, 243, 244
couple, 243
current, 243
pile, 243
Thermo-electricity, 243
Thermometer, 111; weight, 114
Thin plates, colors of, 178
Thunder, 201
Tin, specific gravity of, 56
Tones, 95
Torpedo, 245
Torricellian vacuum, 71
Torricelli's theorem, 62
Torsion, angle of, 41; force of, 41; balance, 41, 188
Total reflection, 147
Toughness, 42
Tourmaline pincette, 180
Trade winds, 249
Transformation of energy, 28
Transparent bodies, 134
Tropical climate, 252
Trumpet, speaking, 90; ear, 90
Twilight, 68
Tympanum, 105
Tyndall, experiments and researches of, 94, 101, 102, 106, 124, 129, 163, 252

UNDERSHOT wheels, 61
Undulation, theory of, 109
Undulatory theory of light, 134
Uniformly accelerated motion, 28
Unison, 94
Unit, of force, 15; of work, 27; thermal, 125
Universal gravitation, 32
Unstable equilibrium, 34

VACUUM, 36; Torricellian, 71; produced by the air-pump, 76; absolute, 77
Valve, safety, 127
Valves, 80
Vane, electrical, 207
Vaporization, 117
Vapors, 117; aqueous, 252
Variable climate, 256
winds, 249
Velocities, table of, 14
Velocity, 14; of sound, 14, 87; of light, 14, 136; of electricity, 215
Ventilators, 121
Vibrations, of pendulum, 25; of sounding bodies, 85; amplitude of, 86; measurement of the number of, 90; graphic method of enumerating, 93; of strings, 94; musical notes dependent on, 95; wave-length deduced from, 96; analysis and representation of, 97; of plates, 97; of membranes, 98; number of, produced by the human voice, 105 (note); perceptible by the ear, 106 (note); of molecules, 109; in the luminiferous ether, 134
Vibroscope, 98
Victoria regia, 131
Virtual focus, 141
image, 142
Viscosity, 45
Visual angle, 175
Vis viva, 109, 110
Vitreous electricity, 196
humor, 174
Vocal chords, 105
Volatile liquids, 117
Volta, experiments by, 219
Voltaic arc, 224
battery, 221

Voltaic couple, 219
current, 223; physiological effects of, 223; heating effects of, 223; luminous effects of, 224; chemical effects of, 223
electricity, 218
induction, 235; law of, 236
pile, 219
Voltameter, 226
Volume, 12

WATER, weight of, 48; greatest density of, 113, 115; boiling-point of, 113; freezing of, 117; index of refraction of, 147; polarizing angle for, 181; decomposition of, 225
Water-level, 51
Water power, 61
Water-spouts, 252
Water-wheels, 61
Watt's engine, 127
Wave length, 96
Wave theory, 184 (note)
Weather charts, 250
glass, 71
Wedge, 22
Wedgewood's pyrometer, 112
Weight, 15; relation of, to power, 18; measure of mass, 39; variation in, 39; affected by form of the earth, 39; by centrifugal force, 40; of gases, 67; of air, 67
Weight thermometer, 114
Wells, artesian, 52
Wheatstone's experiments, 215; telegraph, 231
Wheel and axle, 20
Wheel barometer, 71
Wheel-work, 21
Wheels, friction, 37
Whirl, electrical, 207
Whispering galleries, 89
Whistle, safety, 127
White-light, decomposition of, 155; recomposition of, 157
Wind instruments, 97
Winds, 248; velocity of, 14
Wire, platinum, 42
Wollaston, 159, 175, 226
Wollaston's battery, 221
Work, 27; measure of, 27; unit of, 27; time and, 27
Writing telegraph, 234

ZINC, specific gravity of, 56; use of, in the voltaic circuit, 220



